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Hydroacoustic Evaluation of the Bonneville Dam Prototype Surface Collector in 1999

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Hydroacoustic Evaluation of the Bonneville Dam Prototype Surface Collector in 1999

by Gene R. Ploskey, Larry R. Lawrence

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Peter N. Johnson, Carl R. Schilt

AScI Corporation
1365 Beverly Road
McLean, VA 22101

William T. Nagy

U.S. Army Engineer District, Portland
333 SW First Avenue, Tenth Floor
Portland, OR 97204-3495

Deborah S. Patterson

DynTel, Inc.
3530 Manor Drive
Vicksburg, MS 39180

John Skalski

School of Aquatic and Fishery Sciences
University of Washington
1122 Boat Street, NE
Seattle, WA 98105

Final report

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Portland, OR 97204-3495

Contents

Preface

This report was prepared by the Fisheries Engineering Team (FET), Stevenson, WA, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), Vicksburg, MS, U.S. Army Engineer Research and Development Center (ERDC), with support from the AScI Corporation, McLean, VA, DynTel Corporation, Vicksburg, MS, the U. S. Army Engineer District, Portland, and the University of Washington, Seattle. The research was conducted under the general supervision of Dr. Mark Dortch, Chief, WQCMB; Dr. Richard E. Price, Chief, EPED; and Dr. John W. Keeley, Acting Director, EL. Technical oversight was provided by Mr. Blaine Ebberts of the Portland District.

Many other people made valuable contributions to this study. The Statistical Oversight Committee was attended by two statisticians including Drs. John Skalski, University of Washington, and Cliff Pereira, Oregon State University, as well as by study investigators and sponsors. Ms. Toni Schneider, WQCMB, managed interagency transfers and allocation of funds. Riggers from the Bonneville Project helped with the installation, repair, and removal of hydroacoustic equipment and moved prototype surface collector trashracks to provide slot treatments that were tested. Jessie Seager, *Hands on the Wind*, Stevenson, WA, provided people to maintain all hydroacoustic systems hourly from 1600 to 0800. Schlosser Machine, Hood River, OR, fabricated transducer mounts.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James S. Weller, EN, was Commander.

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Summary

Introduction

This study, which was conducted in spring and summer 1999, evaluated the efficiency and effectiveness of one unit of a prototype surface collector (PSC) for collected juvenile salmon at Powerhouse 1, Bonneville Dam. The 50-ft-deep slots in Intake 5b were configured to have 5- or 20-ft wide openings that were changed according to a blocked experimental design for evaluating effects on fish passage, efficiency, and effectiveness. The PSC, located in front of units 3 through 6, extends 20 ft upstream into the forebay and 50 ft below the surface at maximum pool elevation. It was not intended to be a fish bypass structure but a test facility. As it exists, fish entering the PSC pass through the structure and into the turbine, as opposed to being deposited into a bypass channel in a full-scale collector.

This research project was one of many studies of the US Army Engineer District, Portland to resolve critical uncertainties in the implementation of surface collector technologies at Bonneville Dam. The original goals for 1999 research were as follows:

1. Test hydroacoustic-sampling methods proposed for the year-2000 evaluation of the prototype surface collector (PSC) and identify any potential problems or biases.
2. Evaluate a split-beam deployment upstream of a PSC slot and determine whether it provides estimates of fish passage that can be correlated to estimates from in-turbine transducers.
3. Estimate the efficiency and effectiveness of two adjacent PSC units and determine whether 1998 results hold for adjacent units creating greater downward flow than a single operating unit.

Goal number three could not be realized in 1999 since Unit 6 remained inoperable throughout the sampling seasons. Nevertheless, we did evaluate the performance of a single PSC unit relative to its performance in the previous year.

To facilitate evaluation of PSC performance, the following list of specific objectives were produced:

1. Estimate passage of juvenile salmon through PSC Unit 5 during 2-day, 5- or 20-ft-wide slot treatments.

2. Estimate numbers of juvenile salmon passing under the PSC at unit 5 during 2-day, 5- or 20-ft-wide slot treatments.

3. Test for significant differences in numbers of fish entering and passing under the PSC for the two different slot treatments each season.

4. Estimate fish passage efficiency, where efficiency is the number of fish passing into the PSC divided by the number passing into plus the number passing under the PSC, and test for significant differences in efficiency between treatments each season.

5. Estimate PSC effectiveness, where effectiveness is the ratio of the proportion of fish collected to the proportion of water collected, and test for significant differences in effectiveness between treatments each season.

6. Describe the distribution of observations of fish swimming direction and speed for a forebay area within 2 m of the slot at Unit 5 using split-beam data.

7. Estimate PSC entrance efficiency, where entrance efficiency is the number of fish detected by split-beam transducers with trajectories toward the opening divided by all fish detected regardless of their direction of movement.

8. Compare estimates of collected fish based upon in-turbine sampling with estimates based upon entrance sampling with split-beam transducers.

9. Describe diel trends in fish passage, efficiency, and approach direction.

Materials and Methods

A randomized block experimental design was employed to test for differences in PSC efficiency and effectiveness between two slot widths. It called for successive 2-day treatments of one slot width followed by successive 2-day treatments of the other slot width.

We deployed two pairs of up-and down-looking transducers inside each intake at Unit 5. Each opposing pair of transducers was fast multiplexed for a two-minute period before switching to another opposing pair. One replicate sample was collected every 12 minutes, with five replicates collected each hour. Twenty-three hours of in-turbine hydroacoustic data were collected per day for a total of 36 days in the spring and 40 days in the summer. The 0900 hour was used to download data from acquisition computers.

Fish passing into and fish behaviors in front of the PSC were monitored with two hydroacoustic systems, one provided by the WES and the other by Battelle. Six transducers were deployed as three up- and down-looking pairs on a 50-ft tall, 12-ft wide steel frame, which was placed upstream of the PSC trash racks at turbine intake 5b. Two of the transducer pairs were located on either side of the middle of the slot to sample fish on the north and south sides of the PSC entrance. The third pair was placed in the middle of the slot. The down-looking transducer of each pair was aimed about 7° off the upstream edge of the PSC trash racks and sampled from mid-depth of the PSC slot to the bottom of the forebay. The up-looking transducer of each pair also was aimed about 7° off the upstream edge of the PSC trash racks and sampled from the mid-depth of the PSC slot to the water's surface. Each pair sampled for 10 2-minute periods per hour, 23 hours per day for 36 days in the spring and 40 days in the summer.

In-turbine data were manually processed to identify and count fish traces while split-beam data were process by automated tracking software developed by Mr. William Nagy, U. S. Army Engineer District, Portland. Fish traces upstream of the PSC were classified as passing into, under, or away from PSC slot based upon their direction and speed of travel. All entrance and in-turbine counts of fish were spatially expanded based upon the ratio of passage width to the diameter of the hydroacoustic beam at the range that each fish was detected. Beam diameter was determined by modeling hydroacoustic detectability, which estimated effective beam angles. Counts per hour and their variances were summed to estimate fish passage and its variance for days, treatments, and seasons.

Results

Noise

Dense acoustic noise present during 20-ft slot treatments impaired our ability to identify fish traces in echograms from up looking, in-turbine transducers, especially in the A and C intakes. Fortunately, we were able to compare fish passage metrics among PSC slot treatments using in-turbine counts for 5-ft treatments and entrance counts for 20-ft treatments. Noise was not a problem for in-turbine sampling during 5-ft treatments because the volume of water and associated turbulence passing through the PSC were both reduced.

In-turbine Versus Forebay Estimates

Highly significant correlations of in-turbine estimates of fish that had passed through the PSC with estimates of numbers passing into PSC indicate that split-beam sampling in the forebay can be used to estimate numbers of collected fish. In addition, a significant correlation of passage estimates from the middle pair of split beams with estimates from all three pairs also suggests that a single pair of split beams would be adequate for sampling at each entrance in 2000. The location of each pair should be randomly selected from three lateral positions at each of the six 20-ft slots to provide statistical inference for the whole collector rather than just center positions.

Although highly correlated, in-turbine estimates were about 3.5 times higher than the forebay estimates of fish passage for the 5-ft slot, which suggests that the acoustic screen model for expanding numbers was not appropriate for the 5-ft slot. The acoustic screen model is used to spatially expand the number of detected fish based upon the ratio of the passage width to beam diameter at the range of detection. Geometrically, the acoustic screen is a trapezoid on the axis of the acoustic beam and perpendicular to the direction of fish travel. The acoustic screen model is most appropriate when walls or piers bound the sides of the sample volume, flow is relatively straight through the opening, and fish distributions lateral to flow and across the beam are uniform. The 5- and 20-ft slots were not between piers, and the hydroacoustic beams had to be located upstream of the slots. For the 5-ft slot, a passage width corresponding to the diagonal distance from beam center to the edges of the slot better defined the dimension of the passage that could have been sampled than the 5-ft width. A 20-ft slot is more forgiving than a 5-ft slot for departures from the ideal acoustic-screen model. A 20-ft width divided by the diagonal distance from the center of the hydroacoustic beam to the edges of the entrance (22 ft) was closer to one (0.91) than a similar ratio for the 5-ft slot (5/11.9 ft = 0.42). Consequently, passage estimates for the 20-ft slot were less likely to have been biased by acoustic-screen expansions than estimates for the 5-ft slot. We used the conventional acoustic screen model to expand entrance counts for the 20-ft slot treatment and in-turbine counts for the 5-ft slot treatment that were compared.

Estimates of numbers of fish passing under the PSC are best estimated by sampling with down-looking transducers in turbine intakes rather than upstream of the PSC. Fish sampled deep in the turbine intake are committed to passing and will only be counted once, unlike fish detected below the floor of the PSC, which is 30-ft upstream of the turbine intake. Estimates of numbers passing beneath the upstream edge of the PSC floor were significantly higher than numbers passing at elevations < 30.5 ft inside the turbine.

Variation Among and Within Intakes

Differences among intakes suggest that it would be desirable (if practical) to sample every intake (18) within each of the six PSC units in 2000. We did not detect significant differences in spring during both slot treatments for unguided fish nor during 5-ft treatments for guided fish. However, we found significant differences in both guided and unguided passage among intakes in summer. The uniformity of spring passage distributions and the laterally skewed distributions in summer may result from differences in the swimming abilities of the yearling and sub-yearling fish. Yearling fish migrating in the spring are larger and more developed physiologically than the sub-yearling summer migrants and presumably can maintain their lateral position more effectively than the summer migrants despite circular flows in the A and C modules. In contrast, sub-yearling fish are more likely than yearling fish to be entrained in eddies.

The lateral distribution of fish passage within intakes is another critical element to consider for determining sampling effort for the evaluation in 2000. If fish were uniformly distributed across the intake, a single transducer placed anywhere in an intake would provide adequate coverage for accurately estimating passage. However, lateral distributions of passage within intakes were seldom uniform in 1999 (see Table 4 and Figure 11).

The consequences of non-uniform distributions among and within intakes not only relate to spatial sampling effort but also to the precision of measurements of PSC performance. The PSC passage efficiencies for the 5-ft slot for which we could assess spatial sampling effects averaged 69.4 ± 4.1 % in spring and 66.0 ± 6.5 % in summer. The data indicate that spatial variation among and within intakes accounted for more than 80% of the confidence limits based upon spatial and temporal variation in efficiency estimates.

Allocation of sampling effort for the Year 2000 study should attempt to sample sources of higher variation first, inasmuch as sampling each of 18 intakes and two lateral locations per intake would not be cost effective. The variation among intakes usually was higher than the variation within intakes so the most effective approach would be to sample all intakes first, if possible. Next, multiple positions within the turbine unit with the highest variance could be sampled, if resources permit. This would provide some measure of within-intake variance that could be expanded and incorporated into precision estimates for PSC efficiency.

Vertical Distributions

Vertical distributions of fish in the forebay immediately upstream of the 5- and 20-ft slots in the PSC were significantly different, and numbers and proportions of fish at different depths provide a different view of slot-width effects. Significantly higher numbers of fish immediately upstream of the 20-ft slot than upstream of the 5-ft slot suggests that the wider slot attracts more fish to the vicinity of the entrance than the narrow slot. Cumulative frequencies indicate that proportionally more fish were detected under the 5-ft slot than under the 20-ft slot. Proportions of fish detected below the floor of the 5-ft slot and inside the turbine (29-31 %) were higher than the proportions below the floor upstream of the PSC (18-20 %). This suggests that vertical distributions change significantly between the time that fish contact the PSC and the time they are detected in the turbine downstream.

Differences Between Slot Treatments

The PSC collected significantly more fish during 20-ft treatments than during 5-ft treatments, although we found no significant differences between the two treatments for estimates of fish passing under the PSC in either season. Entrance and slot efficiencies also were significantly higher for the 20- than for the 5-ft treatment. Only PSC effectiveness was higher with the 5-ft treatment, which passed 1780 cfs less water than the 20-ft treatment. The larger flow net produced by the 20 ft slot may provide orientation cues to fish at greater distances than does the less extensive flow net generated by the 5-ft slot. Entrance efficiency estimates, although they may be compromised by multiple counting, also were higher for the 20 ft opening.

Seasonal Trends

Numbers of guided and unguided fish increased from spring through summer but PSC efficiency and effectiveness had limited seasonal trends. Summer efficiencies were only slightly lower than spring efficiencies, which is consistent with earlier results, and efficiency did not drop as precipitously as those associated with in-turbine screens. The drop in entrance efficiency in late summer likely was due to multiple counts of spent American shad wallowing in split-beam sample volumes. The American shad migration through the Bonneville fish ladders began in late May and peaked the third week in June.

Diel Trends

The 5-ft slot not only was less successful at collecting fish than the 20-ft slot, but it also collected fish on a very different schedule, similar to deep passage at a turbine. Passage of guided fish during the 5-ft-slot treatment and unguided fish (either treatment) was higher at night than during the day, which is typical of juvenile salmon passage through turbines without a surface collector. In contrast, guided fish passed more during daytime than at night during the 20-ft treatment, which is the typical pattern for surface passage at a sluiceway. Similarly, passage efficiency had little diel pattern under the 5-ft slot treatment, but increased significantly during the daytime under the 20-ft treatment. Perhaps smolts that passed through the 5 ft opening often did so when they lost visual orientation.

Comparison to 1998 Results

In-turbine data collected in spring 1999 with up-looking transducers during the 5-ft slot treatments suggest that our 1998 assumption that 25 % of the collected fish passed within 8 ft of the intake ceiling was appropriate. In 1998, we increased the estimates of PSC passage by a factor of 1.33 assuming that we sampled 75% of the intake area above the PSC floor and a like percentage of the fish. Multiplying by 1.33 increased fish passage estimates to represent passage for the whole intake. In turbine vertical distributions in 1999 indicate that 27.4 and 32.9 % of the fish passed within 8 ft of the intake ceiling in spring and summer, respectively, and these percentages are close to the 25 % we assumed in 1998.

Nevertheless, 1999 estimates of PSC efficiency and effectiveness for Unit 5 were lower than the mean estimated for units 3 and 5 in 1998. This trend also was observed for radio tagged fish (Hal Hansel and Noah Adams, U. S. Geological Survey; Personal Communications). The 3.4 % efficiency drop for the 20-ft slot in spring (from 87.8 to 84.4 %) was not significant, but the other estimates were significantly lower in 1999 and in 1998. Efficiency for the 5-ft slot in spring decreased from 92.2 % in 1998 to 69.3 % in 1999 and summer efficiency decreased from 84 % in 1998 to 71.3 % in 1999. The 20-ft slot efficiency in summer decreased from 92 % in 1998 to 75 % in 1999. The effectiveness of the PSC also was lower in 1999 than in 1998 for the 5-ft slot treatment in spring and for the 5- and 20-ft slot treatments in summer.

The reason for the differences between the two years is unknown. However, Unit 5 median discharge was 12 % higher in 1999 (median = 11, 291 cfs) than in 1998 (median = 10,100 cfs), except during the last treatment block. Efficiencies during the last test block did not differ much from those observed during earlier blocks but comparing efficiencies for one block to all others is far from conclusive. Unfortunately, the study was not designed to assess the effects of discharge of surface collector performance.

Recommendations

1. The 20-ft PSC slot should be the primary focus of research in 2000 because it outperformed the 5-ft slot in attracting and collecting fish and had a significantly higher efficiency than the 5-ft slot.

2. Sampling with down-looking transducers in turbine intakes downstream of the PSC should be continued to estimate passage of fish under the PSC. Counts of fish in the upper portion of these down-looking beams also will provide a calibration check on estimates of passage through the PSC by split-beam transducers deployed at the slot entrances.

3. If resources are sufficient, every PSC intake at Units 1-6 should be sampled in 2000 by randomly locating a single down-looking transducer in one of three possible positions (right, center, left) in each intake. In addition, three intakes of one unit, preferably the unit with the highest variance, could be sampled with two or more transducers to quantify this spatial component of variance.

4. At least one pair of up- and down-looking split-beam transducers should be deployed at every PSC entrance to estimate numbers of fish entering the PSC and the vertical distribution of passage. These data also will provide supplement behavioral information. The lateral position of each pair of transducers should be randomly selected for every PSC slot.

5. Inter-tracker bias should be controlled by using the same trackers throughout the season and distributing samples among trackers so that average hourly counts have the same bias. Trackers should not be assigned to one system or set of transducers.

6. An ultrasonic repulsion system for American shad should be installed upstream of the PSC unit that will be most intensively sampled with split-beam transducers and the multibeam sonar to reduce intrusion and bias in summer estimate. The system should be evaluated to quantify the scope of the problem and benefits of repelling these non-target species in summer.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
cubic feet / sec (cfs)	0.0283	cubic meters / sec

Introduction

Background

Giorgi and Stevenson (1995) indicated that available biological information was inadequate to design and locate successful surface collector prototypes at Bonneville Dam. They found that information on the vertical and lateral distributions of smolts in forebay areas of both powerhouses and spillway was very limited. No mobile hydroacoustic data had been collected before 1996, and the proportion of smolts approaching Powerhouse 1, the spillway, and Powerhouse 2 had not been estimated.

The Portland District acquired mobile hydroacoustic data on fish distributions in both forebays in 1996 (Ploskey et al. 1998) and 1997 (BioSonics 1998). For Powerhouse 1, these data indicated that higher average fish densities occurred upstream of Units 4-6 in spring and upstream of units 4-6 and 8 and 9 in summer. For Powerhouse 2, average fish densities were highest upstream of units 11-13 adjacent to the south eddy and sluice chute in spring and in summer. Fish densities also were high upstream of Unit 18 in 1996 but not in 1997. Vertical distribution data showed that most fish were in the upper 15 m of the water. The low fish guidance efficiency of many submerged traveling screens at Bonneville Dam would not be expected from examining the vertical distribution of fish these years. If fish did not alter their vertical distributions from what was observed in forebay areas, data from 1996 and 1997 would suggest that fish guidance efficiency usually would exceed 80 %.

Diel (24 hour) patterns of smolt passage are not uniform for either sluiceways (Uremovich et al. 1980; Willis and Uremovich 1981) or the JBS (Hawkes et al. 1991; Wood et al. 1994). Diel passage through the JBS often has a bimodal distribution with a major peak occurring just after dark and a minor peak after sunrise. In contrast, passage through the sluiceway usually is higher during the day than at night (Willis and Uremovich 1981). However, patterns apparently are influenced by the operation of sluice gates, flow, unit outages, and fish species (Willis and Uremovich 1981). Diel patterns of passage have important implications for statistical designs to estimate FPE for all three structures at Bonneville. Diel patterns of turbine passage above and below screens were

estimated in spring and summer 1996 for intakes of Units 3 and 5 at Powerhouse 1 (Ploskey et al. 1998).

Available data from gatewell sampling indicate that the horizontal distribution of smolt passage among intakes at Powerhouse I is not uniform but apparently is influenced by the number and location of operating units and sluice gates as well as the species of juvenile salmon passing (Willis and Uremovich 1981). Interactions among factors may account for a lack of consistency in measures of horizontal patterns. Uremovich et al. (1980) found concentrations of fish at units 6, 7, and 10. Willis and Uremovich (1981), found variable patterns depending on operations, and Krcma et al. (1982), observed most passage at units 4-6.

A prototype surface collector (PSC) was installed at the first powerhouse and tested in 1998. The 40.5-46.5-ft deep slots in intakes 3b and 5b were configured to have 5- or 20-ft wide openings that were changed according to a blocked experimental design for evaluating effects of slot width on prototype fish passage efficiency (PFPE). Two measures of efficiency used were within about 10 % of one another. Data from fixed-aspect hydroacoustic sampling in turbine intakes downstream of the PSC indicated that the PSC had efficiencies of about 90 % in spring and summer. Estimates based upon counts at the PSC entrance averaged about 95 % for the 20-ft slot and 85 % for the 5-ft slot, but estimates potentially were biased by multiple counts of circulating fish in the PSC. Nevertheless, preliminary data indicated that the PSC showed great promise for meeting FPE goals at Powerhouse 1. The FGE of intake screens usually declines precipitously from late spring through summer, but 1998 and 99 results suggest that the collection efficiency of the PSC remains high throughout summer.

Site Description

Construction and evaluation of surface collectors to meet the goal of maximizing fish passage efficiency (FPE) for juvenile salmon passing the Bonneville Project will require extensive research. Project FPE is the fraction of all smolts passing the project by non-turbine routes, and its evaluation requires estimation of smolt passage through all principal routes. Estimation of FPE and quantification of any enhancement by surface collectors will be difficult because the Bonneville Project is among the most complex on the Columbia River. From the Oregon shore north toward Washington, the Project is composed of a navigation lock, a 10-unit Powerhouse 1, Bradford Island, an 18-gate spillway, Cascades Island, and an 8-unit Powerhouse 2. Principal passage routes include the spillway and two powerhouses, but within each powerhouse, passage can be through ice/trash sluiceways, turbines, or the juvenile bypass system (JBS). Smolts enter the JBS after they encounter traveling screens in the upper part of turbine intakes and are diverted to gatewell slots and orifices opening to a bypass channel.

The PSC, located in front of units 3 through 6 (Figure 1), extends 20 ft upstream into the forebay and 50 ft below the surface at maximum pool elevation. It was not intended to be a fish bypass structure. It is a prototype for examining upstream and entrance hydraulics and for testing the efficiency and effectiveness of surface collection before building a full-scale facility. As it exists, fish entering the PSC pass through the structure and into the turbine intake, as opposed to being deposited into a bypass channel in a full-scale collector. In order to evaluate variable entrance slot sizes, the PSC was configured to accommodate slot widths of either 5 or 20-ft in the center intakes of Units 3 and 5.

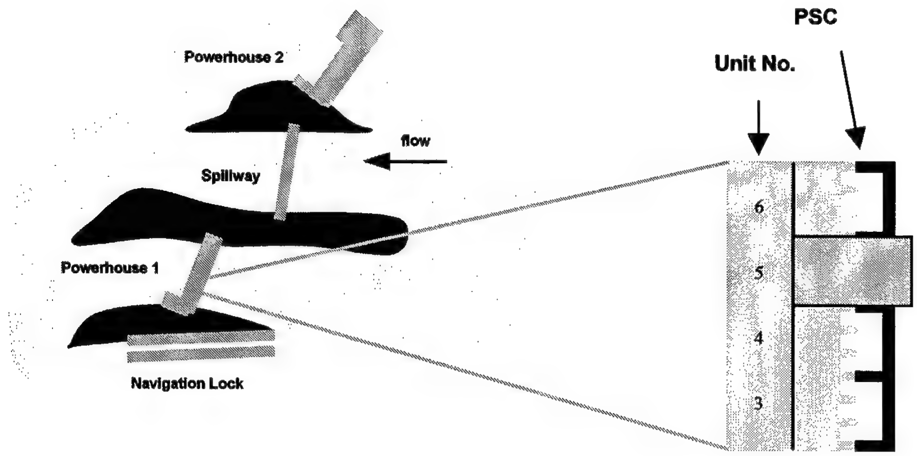

Figure 1. Plan-view drawing of the Bonneville Project showing location of the PSC and the area sampled at Unit 5 (shading).

1999 Research

This research project was one of many studies of the US Army Engineer District, Portland (CENWP) to resolve critical uncertainties in the implementation of surface collector technologies at Bonneville Dam. The program is described in detail in a comprehensive Monitoring and Evaluation developed by the District. Other research efforts in 1999 included monitoring of passage of yearling chinook and steelhead tagged and released at upstream locations by the U. S. Geological Survey. The Pacific Northwest National Laboratory evaluated fish behavior upstream of the Prototype Surface Collector (PSC) entrance at Unit 5 using multi-beam and split-beam sonar techniques. Planning and design are underway to determine optimum out-fall locations and characteristics for volumes of water anticipated from surface bypass development. Plans also are being developed to extend the PSC to include units 1 and 2 at the first Powerhouse for Year 2000 testing. In 1998 and 1999, the PSC covered units 3-6 but was only partially functional in both years because of unit outages. In 1998, the PSC entrances at units 3 and 5 were evaluated, in 1999 only Unit 5 was operational.

In 1998 and 1999, the PSC was not operated as a fish bypass structure. Fish entering the PSC pass through the structure and into the turbine intake. The primary effects evaluated in 1999 were slot velocity (v), and slot discharge (Q) on FPE and effectiveness. The study also will verify that proposed hydroacoustic sampling is adequate to detect differences in treatments and to identify ways to improve sampling.

Goals

The original goals for 1999 research were as follows:

1. Test hydroacoustic sampling methods proposed for the year-2000 evaluation of the prototype surface collector (PSC) and identify any potential problems or biases to assure that sampling will be adequate.

2. Evaluate a split-beam deployment upstream of a PSC slot and determine whether it provides estimates of fish passage that can be correlated to estimates from in-turbine transducers.

3. Estimate the efficiency and effectiveness of two adjacent PSC units and determine whether 1998 results hold for adjacent units creating greater downward flow than a single operating unit.

Goal number three could not be realized in 1999 since Unit 6 remained inoperable throughout the sampling seasons. Nevertheless, we did evaluate the performance of a single PSC unit relative to its performance in the previous year.

Objectives

To facilitate evaluation of PSC performance, the following list of specific objectives were produced:

1. Estimate passage of juvenile salmon through PSC Unit 5 during 2-day, 5- or 20-ft-wide slot treatments.

2. Estimate numbers of juvenile salmon passing under the PSC at unit 5 during 2-day, 5- or 20-ft-wide slot treatments.

3. Test for significant differences in number of fish entering and passing under the PSC for different slot treatments each season.

4. Estimate fish passage efficiency, where efficiency is the number of fish passing into the PSC divided by the number passing into plus the number passing under the PSC, and test for significant differences in efficiency between treatments each season.

5. Estimate PSC effectiveness, where effectiveness is the ratio of the proportion of fish collected to the proportion of water collected, and test for significant differences in effectiveness between treatments each season.
6. Describe the distribution of observations of fish swimming direction and speed for a forebay area from within -2 m of the slot at Unit 5 using split-beam data.
7. Estimate PSC entrance efficiency, where entrance efficiency is the number of fish detected by split-beam transducers with trajectories toward the opening divided by all fish detected regardless of their direction of movement.
8. Compare estimates of collected fish based upon in-turbine sampling with estimates based upon entrance sampling with split-beam transducers.
9. Describe diel trends in fish passage, efficiency, and approach direction.

Materials and Methods

A randomized block experimental design (Table 1) was employed to test for differences in PSC efficiency and effectiveness among variable PSC-slot widths. The original randomized block design called for successive 2-day treatments of one slot width followed by successive 2-day treatments of the other slot width.

Table 1. Revised schedule of randomized vertical slot treatments for 1999 PSC evaluation.

Gregorian Date	Julian Date	Day of Week	PSC Openings (ft)	PH1 Action Item	PSC Block	Gregorian Date	Julian Date	Day of Week	PSC Openings (ft)	PH1 Action Item	PSC Block
SPRING						SUMMER					
						6/5/99	156	Sat	20		1
						6/6/99	157	Sun	20		1
						6/7/99	158	Mon	5	change	1
						6/8/99	159	Tue	5		1
4/30/99	120	Fri	20		1	6/9/99	160	Wed	5		2
5/1/99	121	Sat	20		1	6/10/99	161	Thu	5		2
5/2/99	122	Sun	5	change	1	6/11/99	162	Fri	5	change	3
5/3/99	123	Mon	5		1	6/12/99	163	Sat	5		3
5/4/99	124	Tue	20	change	2	6/13/99	164	Sun	5		4
5/5/99	125	Wed	20		2	6/14/99	165	Mon	5		4
5/6/99	126	Thu	5	change	2	6/15/99	166	Tue	20	change	2
5/7/99	127	Fri	5		2	6/16/99	167	Wed	20		2
5/8/99	128	Sat	5		3	6/17/99	168	Thu	20		3
5/9/99	129	Sun	5		3	6/18/99	169	Fri	20		3
5/10/99	130	Mon	20	change	3	6/19/99	170	Sat	20	change	4
5/11/99	131	Tue	20		3	6/20/99	171	Sun	20		4
5/12/99	132	Wed	5	change	4	6/21/99	172	Mon	5	change	5
5/13/99	133	Thu	5		4	6/22/99	173	Tue	5		5
5/14/99	134	Fri	20	change	4	6/23/99	174	Wed	20	change	5
5/15/99	135	Sat	20		4	6/24/99	175	Thu	20		5
5/16/99	136	Sun	20		5	6/25/99	176	Fri	20		6
5/17/99	137	Mon	20		5	6/26/99	177	Sat	20		6
5/18/99	138	Tue	5	change	5	6/27/99	178	Sun	5	change	6
5/19/99	139	Wed	5		5	6/28/99	179	Mon	5		6
5/20/99	140	Thu	5		6	6/29/99	180	Tue	5		7
5/21/99	141	Fri	5		6	6/30/99	181	Wed	5		7
5/22/99	142	Sat	20	change	6	7/1/99	182	Thu	20	change	7
5/23/99	143	Sun	20		6	7/2/99	183	Fri	20		7
5/24/99	144	Mon	5	change	7	7/3/99	184	Sat	20		8
5/25/99	145	Tue	5		7	7/4/99	185	Sun	20		8
5/26/99	146	Wed	20	change	7	7/5/99	186	Mon	5	change	8
5/27/99	147	Thu	20		7	7/6/99	187	Tue	5		8
5/28/99	148	Fri	20		8	7/7/99	188	Wed	5		9
5/29/99	149	Sat	20		8	7/8/99	189	Thu	5		9
5/30/99	150	Sun	5	change	8	7/9/99	190	Fri	20	change	9
5/31/99	151	Mon	5		8	7/10/99	191	Sat	20		9
6/1/99	152	Tue	5		9	7/11/99	192	Sun	20		10
6/2/99	153	Wed	5		9	7/12/99	193	Mon	20		10
6/3/99	154	Thu	20	change	9	7/13/99	194	Tue	5	change	10
6/4/99	155	Fri	20		9	7/14/99	195	Wed	5		10

Reversed from original schedule
Chain gate at EL 72 ft
Chain gate at EL 70 ft

However, the original design had to be modified on 11 June when the crane used to change the slot width broke down.

The chain gate at Unit 5 B slot was closed initially and then lowered to elevation 72 ft on 19 May (during the last day of the 5th test block). It was lowered again to elevation 70 ft on 3 June (during the 3rd day of the 9th test block) where it stayed for the remainder of the study. Unit 5 operation varied throughout the study period, but discharge averaged 11,049 cfs (range =0-12,705 cfs; median = 11,291) except for the final experimental block (11-14 July) when discharge was reduced to match the 1998 operation conditions (i.e. about 10,000 cfs).

In-turbine Sampling

We used a BioSonics, Inc. ES 2000 echosounder multiplexing twelve single-beam 420-kHz 6° transducers to monitor fish passage in-turbine. The sounder was controlled with BioSonics Dual-beam Multiplex software running on a 66 MHz Austin laptop computer with a BioSonics Echo Signal Processing Board. We deployed two pairs of up-and down-looking transducers per intake at Unit 5. Down-looking transducers were mounted on the downstream side and top of the second trash rack (Figure 2). They were aimed downward, 22° off the plane of the trash racks (11° off vertical). Transducers used to monitor the north side of each intake were placed 6.7 ft from the north edge of the trash rack and transducers monitoring the south side of each intake were placed 6.7 ft from the south edge of the racks.. Up-looking transducers were mounted on the

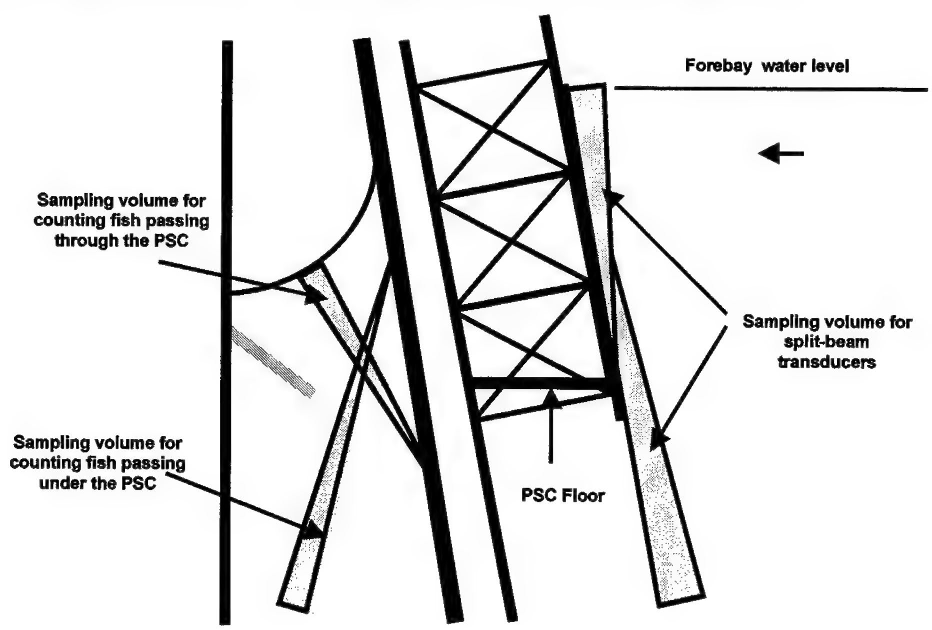

Figure 2. Cross-section of an intake at Unit 5 showing the location of the hydroacoustic monitoring beams for estimating fish passage into and below the PSC.

downstream side and bottom of the fifth trash rack (Figure 2) and aimed 22° off the plane of the trash rack slots (33° off vertical). Up-looking transducers per intake were spaced apart in the same manner as the down-looking transducers. The spatial coverage of intake areas of Unit 5 was high (Figure 3).

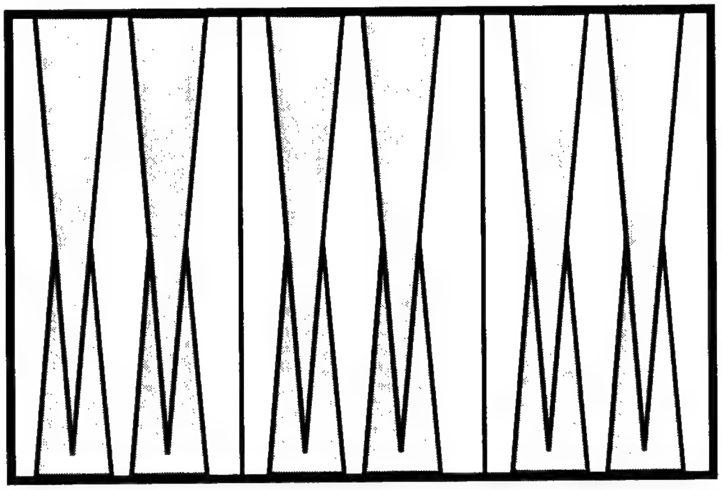

Figure 3. Front view of Unit 5 showing six pairs of up- and down-looking transducer beams and the relative spatial coverageof the intake slots.

Each opposing pair of transducers was fast multiplexed at a rate of 20 pings per second (10 pings per second each) for a two-minute period before switching to another opposing pair. One replicate sample was collected every 12 minutes, with five replicates collected each hour. Twenty-three hours of in-turbine hydroacoustic data were collected per day for a total of 36 days in the spring and 40 days in the summer.

PSC Entrance Sampling

Fish passing into and fish behavior in front of the PSC were monitored with two hydroacoustic systems manufactured by Precision Acoustic Systems (PAS). System 1, provided by ERDC, consisted of one pair of 6° split-beam transducers, a PAS 103 Multi-Mode Scientific Sounder and a PAS 203 Surface Multiplexer. Battelle Northwest (PNNL) provided System 2, which was configured much like the first system except it sampled two pairs of transducers using a remote underwater multiplexer. Both systems were controlled by Hydroacoustic Assessment Research Program (HARP) software run on IBM compatible PCs. The transducers were mounted on a 50-ft tall, 12-ft wide steel frame, which was placed upstream of the PSC trash racks at turbine intake 5b (Figure 2). Two of the transducer pairs (System 2) were located 6.6 ft to either side of the middle of the slot to sample fish on the north and south sides of the PSC entrance. The third pair (System 1) was placed in the middle of the slot to sample fish near the center of the entrance. The down-looking transducer of each pair was aimed about 7° off the upstream edge of the PSC trash racks and sampled from mid-depth of the PSC

slot to the bottom of the forebay (Figures 2 and 4). The up-looking transducer of each pair also was aimed about 7° off the upstream edge of the PSC trash racks and sampled from the mid-depth of the PSC slot to the water's surface. Opposing transducers on the north (Washington side) and in the middle were fast-multiplexed at 16 pings per second (8 pings per second each). The pair on the south side was fast multiplexed at 20 pings per second or 10 pings per second each. Each of the three pairs of transducers covered over 50 % of the PSC opening and nearly all of the area under the PSC and upstream of the middle intake of Unit 5 (Figure 4). Each pair sampled 10 2-minute periods per hour, 23 hours per day for 36 days in the spring and 40 days in the summer.

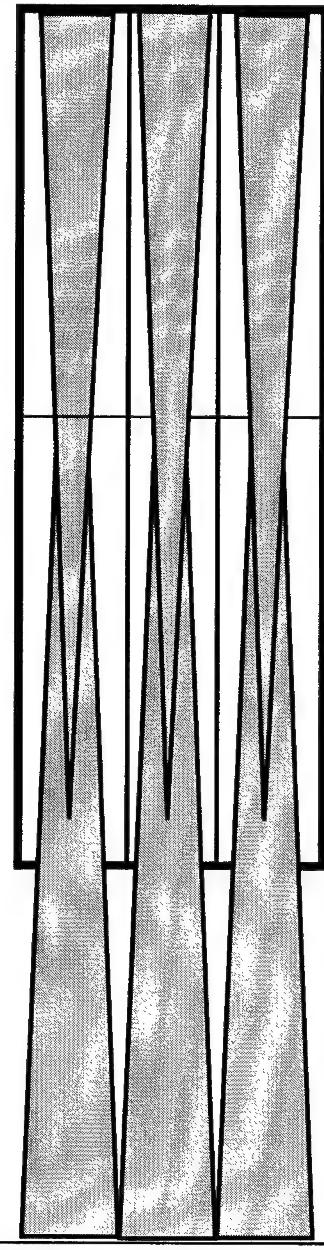

Figure 4. Front view of the PSC opening at Unit 5 showing the coverage of three pairs of split-beam transducers relative to the size of the openings.

Data Handling and Processing

In-Turbine

Data from the previous days in-turbine sampling were down-loaded and archived each morning from 0900 to 1000. Copies of archival data sets were stored temporarily on 1 GB Jaz cartridges before permanent storage on writable CD's. In-turbine data were acquired as hourly .DAT files, the output file format from Biosonics Inc. ESP-DBM data acquisition software. DAT files were translated into a format that was read into a tracking program (FET Tracker) recently developed by William T. Nagy, USAE FFU. We used FET Tracker to display the hydroacoustic data in echogram form and save the user-selected fish traces in output files that were later read into SAS for statistical analysis. The FET Tracker automatically opens successive input files and has several display schemes for color coding by echo amplitude. This later feature is especially important in noisy environments when low amplitude echoes from bubble clouds can diminish the ability to distinguish fish traces from noise.

We defined and counted fish based on a number of trace criteria. Fish traces spanning fewer than four or more than forty-two echoes

were not accepted. In low-noise environments, a three-ping gap (three pings without an echo) was the maximum accepted. In high-noise environments, the maximum was a one-ping gap. Fish detected in a down-looking beam 1.6 ft below the elevation of the PSC floor and above the elevation of the intake floor (32 to 57 ft from the transducers) were counted as passing under the PSC slot. Fish detected above the elevation of the PSC floor and below the intake ceiling (19 to 47 ft from transducers) in up-looking beams were counted as collected. We defined slope criteria for unguided fish based upon beam geometry and the direction of in-turbine flow. Only traces with downward trajectories were accepted. We had no slope criteria for guided fish traces.

We tracked 60% of each hour of in-turbine acoustic data when 3 or more replicates were collected in the hour. When greater than 2 and less than 3 replicates were collected, then we tracked 40% of the hour. Hours with fewer than 2 replicates due to equipment failure were discarded. Equipment failures made up less than 1% of all hours sampled. Hours with missing fish data were estimated using standard linear interpolation techniques. All in-turbine counts of fish were spatially expanded based upon Equation 1 below and counts and variances were expanded to a whole hour using methods described in Appendix A.

$$\text{EXP\_FISH} = \text{PW} / (\text{Mid\_R} \times \text{TAN}(\text{B0}/2) \times 2) \qquad 1$$

where EXP_FISH is the expanded number of fish, PW is half the passage width in meters, TAN is the tangent, and B0 is the effective beam angle in degrees, as determined by detectability modeling (see below).

We performed additional data processing of echo strength and target strength distributions after fish tracking was completed. We translated NMFS length-frequency distribution data acquired from the Bonneville PH1 sampler to echo strength frequency using Love's (1977) equation relating target strength at any aspect to fish size. After comparing in-turbine echo-strength distributions and split-beam target strength distributions to the translated length-frequency data, we applied correction factors (+ 7.5 dB in spring and + 3dB in summer) to the in-turbine distributions. The correction aligned modes of all distributions and made the echo strengths of in-turbine data approximate realistic acoustic sizes of fish. We then applied filters based on mean echo strengths of fish traces. In the spring, any fish trace with a mean echo strength greater than –39 dB or less than – 56 dB was discarded. Beginning on Julian Day 166 in the summer migration season, we applied a filter to reject any fish with mean echo strengths greater than – 45 dB (135 mm). This latter filter was designed to remove many American shad from the data set.

PSC Entrance

Data from the previous day's sampling with split-beam systems at the PSC entrance were down loaded and archived each morning from 0900 to 1000, and copies were stored temporarily on 1 GB Jaz cartridges before permanent storage on compact disks. Data were acquired as hourly *.TS4 files, the output file format of Hydroacoustic Technologies HARP software. A subset of data collected in spring and early summer was manually tracked by Battelle researchers using software developed by William T. Nagy, CENWP. All split-beam data collected in spring and summer were processed by a calibrated autotracker that also was developed by William Nagy. Battelle researchers are independently evaluating the performance of the autotracking software and those results will be presented in their final report. All estimates derived from split-beam data and presented in this report were based upon automated tracking.

There were two passes of the autotracker through every echogram to identify fish. On the first pass, the selection criteria for candidate traces were four or more echoes with a core of three consecutive echoes and no more than a three-ping gap. On the second pass through the data, traces were linked together if their adjacent ends had similar slopes and would intersect if projected 5-pings forward from the first traces and 5-pings back from the second trace.

Fish traces were classified as passing into, under, or away from PSC slot based upon their direction and speed of travel. Echo traces moving toward the PSC slot opening at >1 cm / ping (0.8-0.1 m / sec) were counted as collected by the PSC if they were > 22.6 ft from an up-looking transducer or 22.6 to 40 ft from a down-looking transducer. In general, traces had to be in the upper part the up-looking beams or the lower part of the down-looking beam. Detected fish were expanded at the range of detection using Equation 1 above, where passage width (PW) was 7.5 ft for the sides and 5 ft for the middle of the 20-ft wide slot.

Passage width was 5-ft for the 5-ft wide slot treatment, but we also experimented with other expansions for several reasons. First, the ratio of passage width to beam diameter was small for the 5-ft slot treatment. Second, hydroacoustic beam was upstream of the opening and not bounded by piers which would be more typical of the acoustic screen model for expanding counts to the width of a passage route. Third, under the 5-ft slot treatment, the number of fish moving out of the PSC and down into the upper part of the intake were 3-4 times higher than the number passing into the PSC slot (see Results below).

We considered an alternative way of expanding fish for the 5-ft slot opening because the acoustic screen model did not seem appropriate for the 5-ft slot width. Fish approaching the 5-ft slot had more space to pass on either side of the center pair of hydroacoustics beam than indicated by ratio of the passage-route width to the beam diameter (Figure 5). Consequently, we counted fish moving through all three pairs of split-beams if they were moving toward the opening or the 6-fps

flow into the opening where the probability of entrainment into the slot was high. The purpose was to try to explain higher in-turbine counts than split beam counts (i.e., what does it take to make them equal?). Spatially expanded counts of fish passing into the PSC and associated within-hour variances were expanded to the full hour as described in Appendix A. Counts per hour and their variances were summed to estimate fish passage and its variance for days, treatments, and seasons.

Detectability Modeling

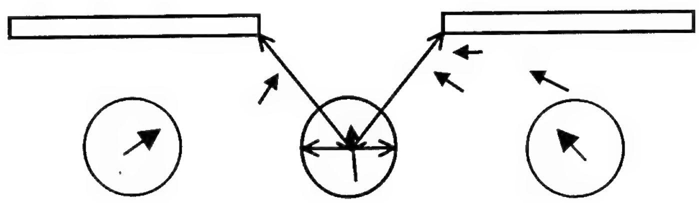

Figure 5. Plan view of the 5-ft slot opening and the cross section of the three up-looking beams from split-beam transducers. The diagonal arrows from the center of the middle beam to the edges of the slot indicate the relative amount of space fish had to pass into the slot.

The effective beam angles (EBA) for the various hydroacoustic deployments were derived by estimating EBA based upon target strengths (EBA_{TS}) and range strata from transducers (EBA_R). Target strength distributions were estimated from split-beam data acquired upstream of the PSC opening. Estimation of EBA_{TS}, a technique developed by Dr. John Ehrenberg (circa 1985), entails determining the relationship between target strength/threshold and effective beam angle relative to nominal beam angle (Figure 6). We estimated EBA_{TS} for each four-day test block.

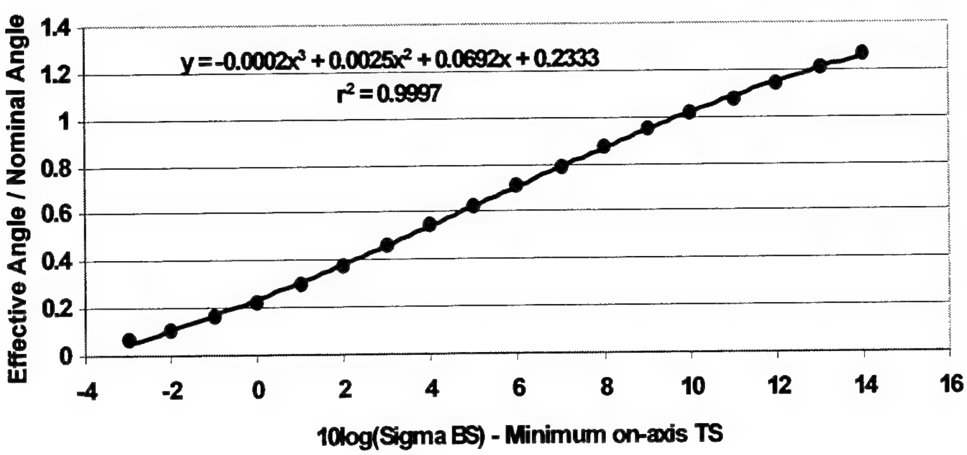

Figure 6. Relationship between the effective beam angle relative to nominal beam angle and target strength/target strength threshold.

Estimation of EBA_R was accomplished by assuming a nominal beam width of 6° in a detectability model developed by BioSonics, Inc. The model uses inputs

of the nominal beam angle parallel and perpendicular to the direction of fish movement across the beam, fish velocity, pulse repetition rate, echoes required for detection, transducer orientation from vertical, and fish trajectory angle. Effective beam angles output from the model are then normalized and plotted by range (Figure 7). The overall effective beam angle is then calculated as the product of the EBA_{TS} and the normalized EBA_R.

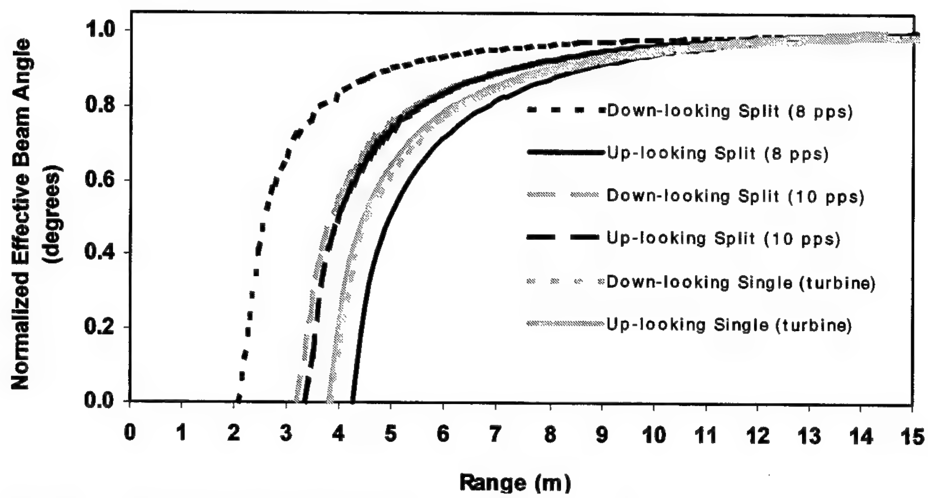

Figure 7. Normalized effective beam angle as a function of range for each hydroacoustic deployment used at Bonneville in 1999.

Metrics

We used the following variables and metrics to evaluate the performance of the PSC and assess sampling methods proposed for the YR 2000:

1. Guided Fish Passage – fish that passed into the PSC, as determined by sampling either in turbine or out in front of the PSC entrance.

2. Unguided Fish Passage – fish that passed under the PSC, as determined by sampling in-turbine

3. PSC Efficiency – ratio of guided fish passage to total fish passage guided fish/(guided + unguided fish)

4. PSC Effectiveness - the ratio of the proportion of fish collected to the proportion of water collected

5. Entrance Efficiency - the number of fish detected within 3 to 10 ft of the PSC entrance with trajectories toward the opening divided by all fish detected regardless of their direction of movement

6. Calculation of metrics and associated variances are described in Appendix A.

Results

Noise Limitations

In-turbine counts of fish passing through the PSC were not reliable during 20-ft slot treatments because of dense acoustic noise created by turbulence within the PSC. During 20-ft slot treatments, large volumes of entrained air were concentrated in the upper water column of the turbine intake. Echoes from air bubbles resulted in high densities of echoes that reduced our ability to distinguish fish from noise with the up-looking, in-turbine beams (Figure 8). Noise limitations were most persistent in the A and C slots than in the center (B) slot. During 5-ft treatments, however, counts of fish passage through the PSC were reliable as in-turbine noise levels were much lower (Figure 9).

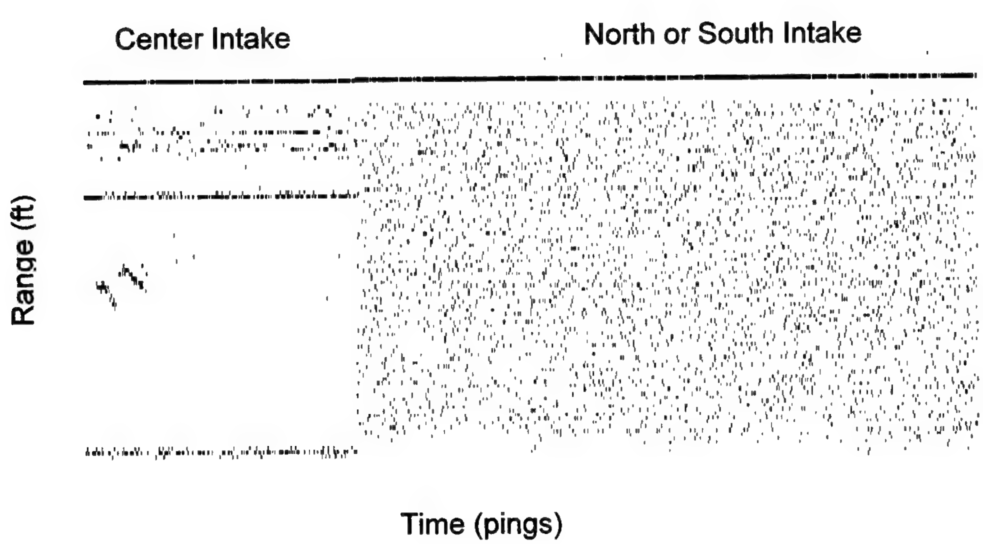

Figure 8. Typical echogram from up-looking transducers showing the presence of noise in the in-turbine environment during 20-ft slot treatments, particularly for the north or south intake of Unit 5.

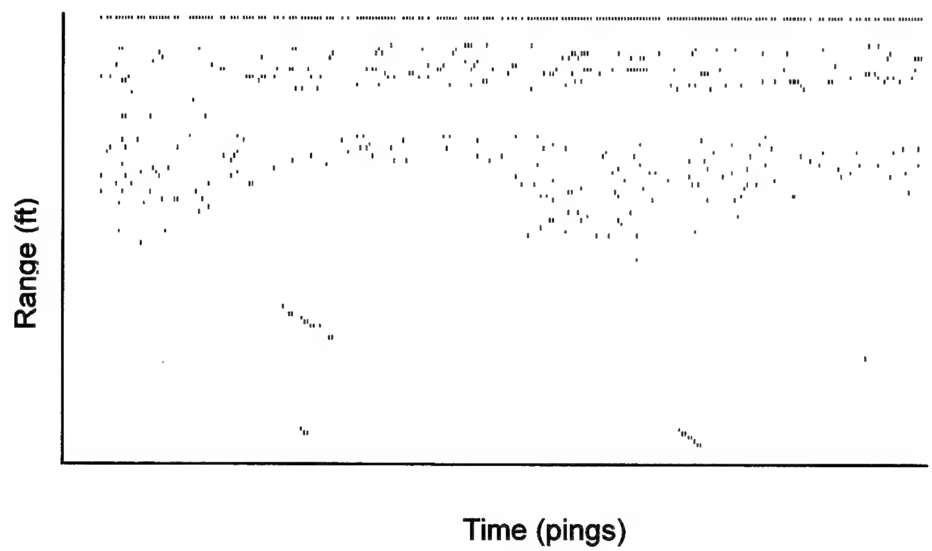

Figure 9. Typical echogram from up-looking transducers in any slot during 5-ft slot treatments. Note the general absence of noise in the in-turbine environment as compared to a typical echogram from the north or south slot during the 20-ft treatments (Figure 8).

In-turbine Sampling

Vertical distribution

Based on fish counts during 5-ft slot treatments, in-turbine vertical distributions were generally similar in spring and summer (Figure 10). However,

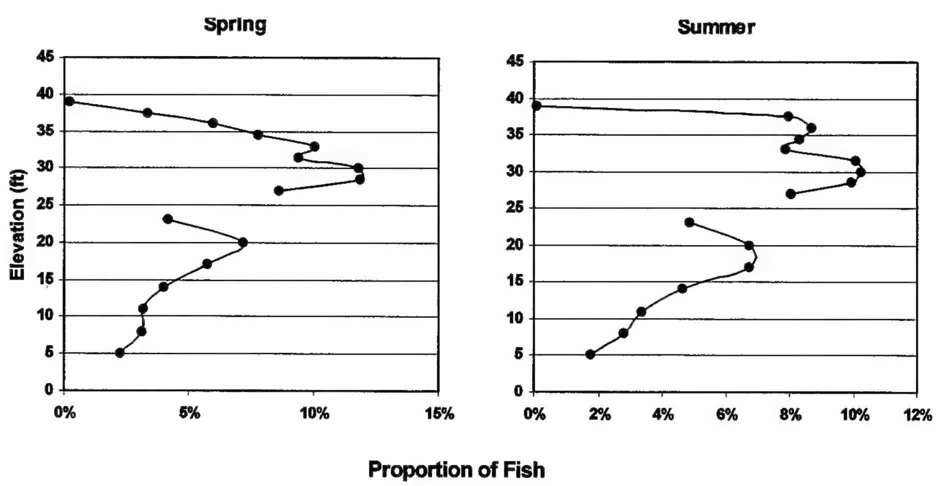

Figure 10. Vertical distributions of in-turbine fish passage estimates during 5-ft slot treatments for spring (left) and summer. Plots illustrate distributions of guided fish based upon up-looking transducers (upper portions) and unguided fish based upon down-looking transducers. The gap between the upper and lower portions reflect the elevations that were not sampled.

there were slight differences in guided and unguided fish distributions between seasons. Peak concentrations of guided fish (upper portion of plots in Figure 10) were slightly deeper in spring than in summer. The opposite was true for unguided fish (lower portion of plots in Figure 10), where peak concentrations were slightly deeper in summer than in spring.

Differences Among Intake Slots

In summer, we found significant differences among intake counts of guided fish during 5-ft slot treatments and in unguided fish during both slot treatments but found no differences in spring (Table 2). To further investigate apparent differences in fish passage among intakes during the summer season, we compared passage estimates between pairs of intakes (Table 3). For estimates of guided fish with 5-ft slot treatments, we detected significantly greater numbers at Intake C than at intakes A and B. Unguided fish numbers during either slot treatment were significantly lower in Intake B as compared to intakes A and C.

Table 2. Results from Kruskal-Wallis Test comparing guided and unguided fish passage estimates among intakes at Unit 5 by season and slot treatment.

Season	Slot Treatment	Test Days (N)	Prob. > CHISQ Guided Fish	Prob. > CHISQ Unguided Fish
spring	5	18	0.6538	0.3021
spring	20	18	n / a	0.6296
summer	5	20	0.0001	0.0001
summer	20	20	n / a	0.0001

Table 3. Results from Wilcoxon 2-Sample Rank Sum Test comparing guided and unguided fish passage estimates between intakes at Unit 5 by slot treatment for the summer season (N = 20 test days for each comparison).

Comparison	Guided Fish 5-ft Slot	Prob > | Z |	Unguided Fish 5-ft Slot	Prob > | Z |	Unguided Fish 20-ft Slot	Prob > | Z |
A vs. B	B > A	0.0001	A > B	0.0006	A > B	0.0161
B vs. C	C > B	0.0001	C > B	0.0001	C > B	0.0001
A vs. C	C > A	0.0001	C = A	0.2559	C > A	0.0058

Differences Within Intake Slots

Lateral distributions of fish passage within intakes of Unit 5 were seldom uniform (Figure 11; Table 4). The most prevalent skew in distribution occurred at Intake C with unguided fish passage, where the south side yielded significantly

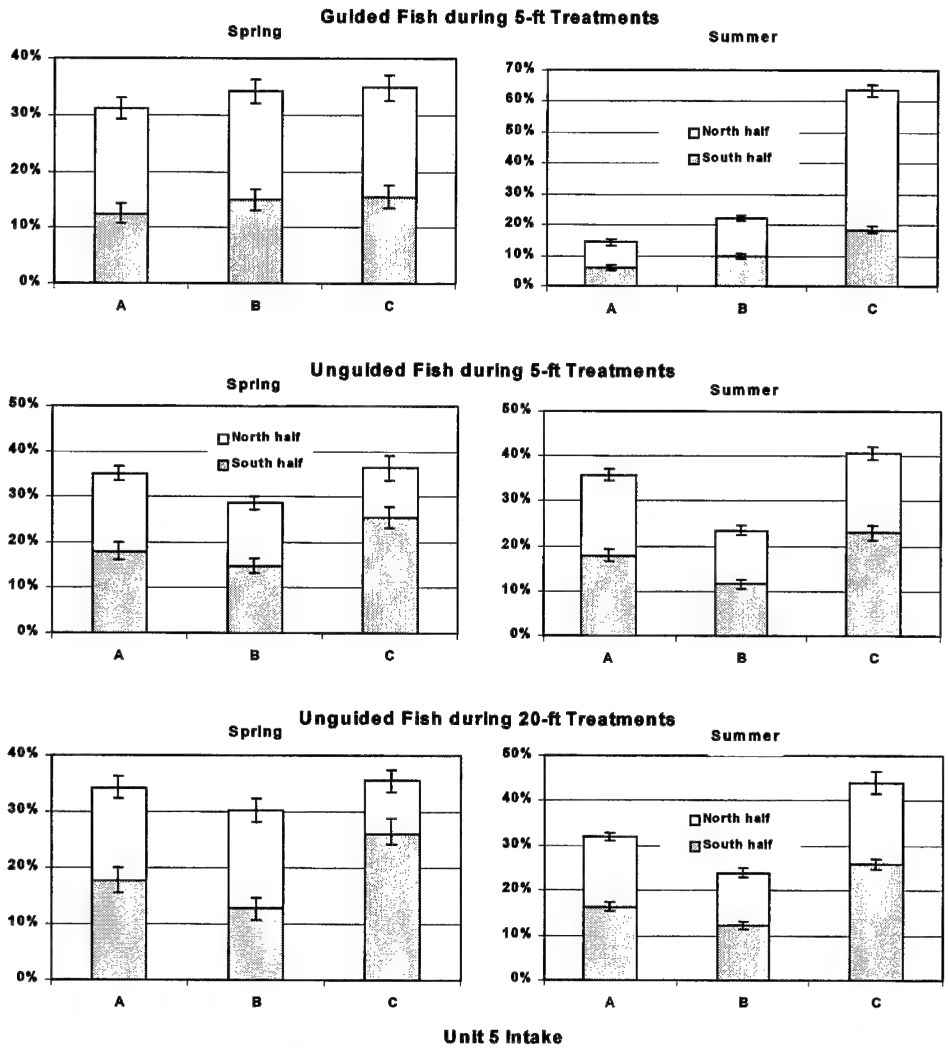

Figure 11. Proportions of fish passage among and within intakes of Unit 5 for spring (left) and summer (right). Guided fish during 5-ft treatments are shown in the upper plots, unguided fish are shown during 5-ft (middle plots) and 20-ft treatments (lower plots). Proportions of fish within intakes are illustrated with light (north half) and dark (south half) bars. Error bars reflect 95% confidence limits.

greater passage than the north side across slot treatment and season. Guided fish passage was significantly greater through the north side of intakes A and C in spring and in all intakes in summer.

PSC Entrance Sampling

The only valid comparison of in-turbine counts with split-beam counts immediately upstream of the PSC was for the 5-ft-slot treatment in spring and summer when we could track fish passing through up-looking, in-turbine transducer beams. In-turbine counts of fish passing out of the PSC were highly

Table 4. Results from Wilcoxon Sign Rank Test comparing guided and unguided fish passage estimates between locations within intakes of Unit 5 by slot treatment and season. Locations within intakes are labeled as n (north) and s (south). Significant differences are indicated by showing the nature of the relationship between intake locations. Numbers in parentheses indicate probability values (Pr>=| S |). The sample size (N) reflects the number of test days per season.

		INTAKE A			INTAKE B			INTAKE C		
Season	Slot	N	Guided	Unguided	N	Guided	Unguided	N	Guided	Unguided
spring	5	18	n > s (0.002)	no diff	16	no diff	no diff	18	n > s (0.014)	s > n (0.0001)
spring	20	18	n / a	no diff	16	n / a	n > s (0.001)	18	n / a	s > n (0.0001)
summer	5	20	n > s (0.005)	no diff	20	n > s (0.004)	no diff	20	n > s (0.0001)	s > n (0.0001)
summer	20	20	n / a	no diff	20	n / a	no diff	20	n / a	s > n (0.0002)

correlated with split-beam counts of fish passing into the PSC (Figure 12). Slopes of correlation lines with intercepts forced through zero indicated that 3.5-3.6 times more fish were detected leaving the PSC than were counted entering it. Summing counts of fish passing through the 3 pairs of split beams toward the 5-ft opening made the slopes of correlation lines much closer to unity (Figure 13).

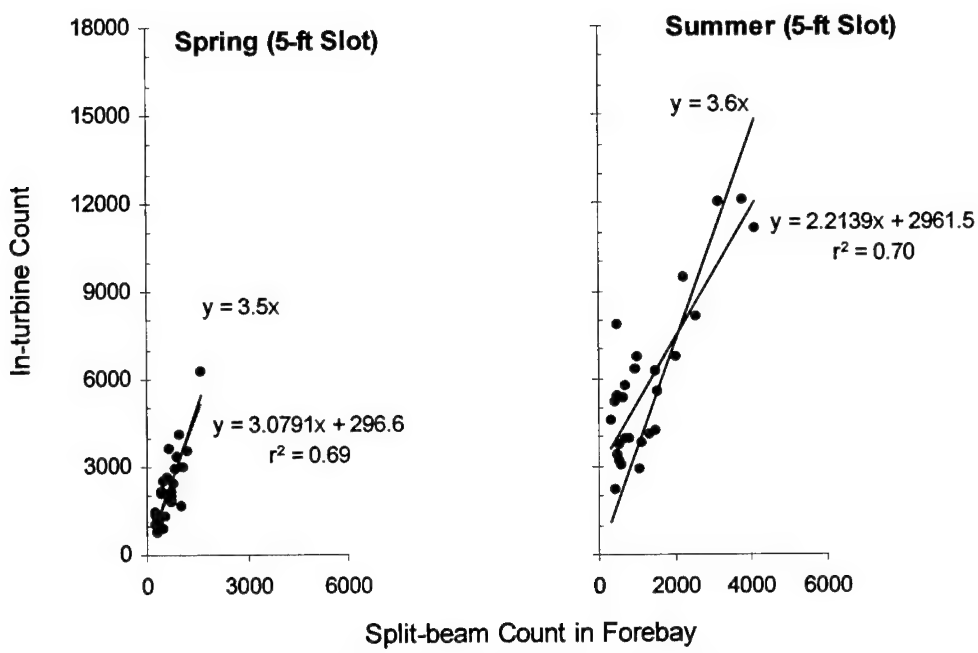

Figure 12. Correlations of in-turbine counts downstream of the PSC with split-beam counts at the PSC entrance.

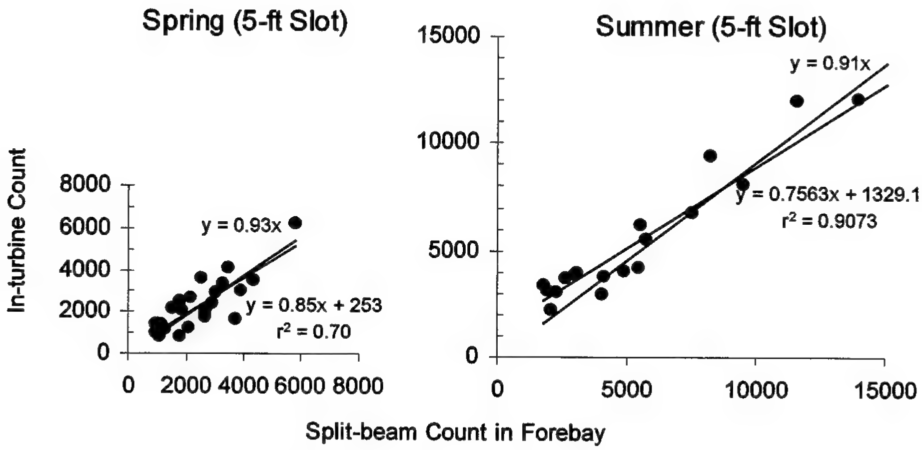

Figure 13. Correlations of in-turbine counts of fish passing out of the PSC with counts of fish moving toward the PSC entrance through 3 pairs of split-beams located immediately upstream of the PSC.

Expanded numbers of uncollected fish counted in the turbine intakes downstream of the PSC also were highly correlated with expanded counts made in the forebay with split-beam transducers (Figure 14). The slope of the correlation line indicates that about 2.5 times more fish were detected upstream and below the PSC floor than were detected in the down-looking beam inside the turbine intake.

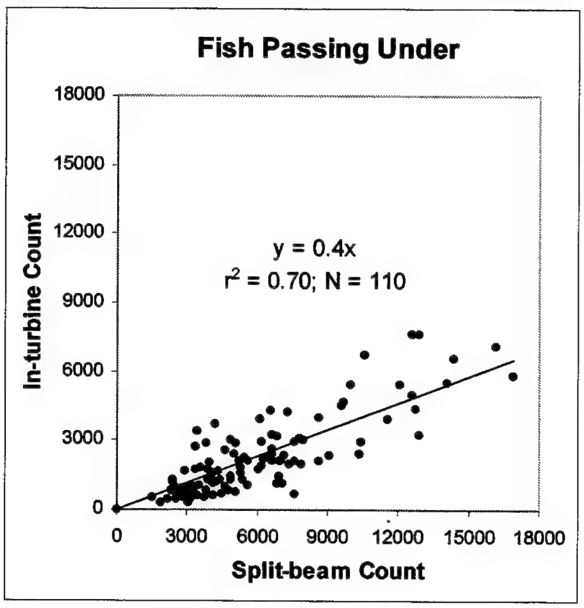

Figure 14. Correlation of in-turbine counts of fish that passed under the PSC with split-beam counts of fish moving under the front of the PSC 30 ft upstream.

Expanded counts from the three pairs of split-beams upstream of the PSC entrance were very highly correlated with expanded counts from the middle pair of split beam transducers (Figure 15). The slope of the correlation line indicates that the middle pair underestimated passage by 29 % relative to the estimates by all transducers. This indicates that the distribution of passage across the 20-ft wide slot was slightly skewed away from the middle.

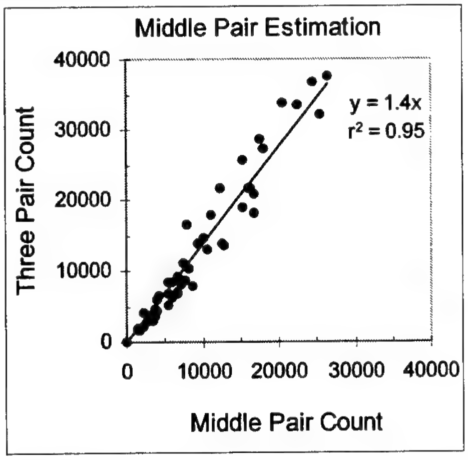

Figure 15. Correlation of expanded counts of fish by three pairs of split-beams transducers across the 20-ft wide slot entrance in the PSC with the expanded count by the middle pair only.

Vertical distributions

In spring, the vertical distribution of fish upstream of the PSC was strongly skewed toward the upper water column and many more fish were detected upstream of the 20-ft slot than upstream of the 5-ft slot (Figure 16). Cumulative frequency data in the figure indicate that over 80 % of the fish upstream of the 5-ft slot were detected above elevation 30.5 ft where the PSC floor was located. For the 20-ft slot about 95 % were above elevation 30.5 ft.

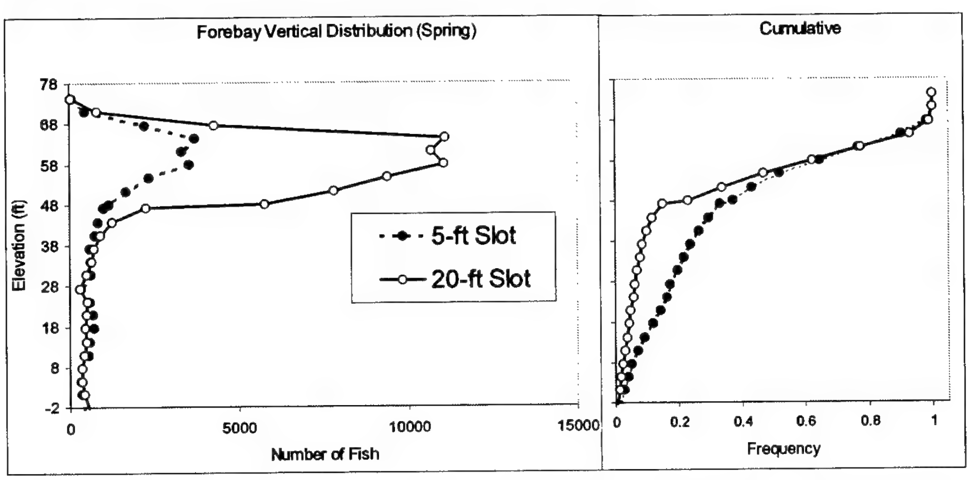

Figure 16. Vertical distributions of smolt-sized fish immediately upstream of 5 and 20-ft wide slots in the PSC in spring 1999.

In summer, the vertical distribution was again strongly skewed toward the water's surface and about four times more fish were detected upstream of the 20-ft slot than were counted upstream of the 5-ft slot (Figure 17). About 82 % of the fish were above the elevation of the PSC floor during 5-ft slot treatments, whereas 92 % were above the PSC floor during 20-ft treatments.

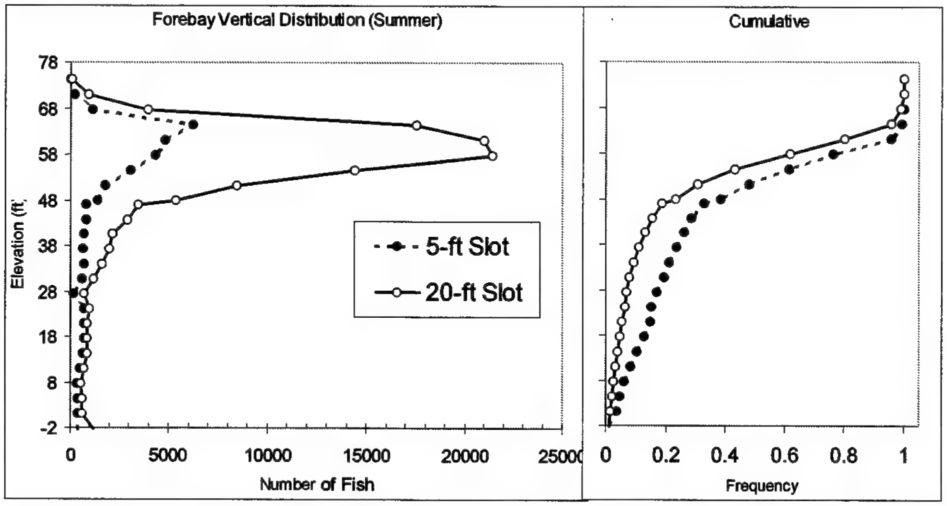

Figure 17. Vertical distributions of smolt-sized fish immediately upstream of 5 and 20-ft wide slots in the PSC in spring 1999.

PSC Evaluation

<u>Differences in Slot Treatments</u>

Prototype surface-collector efficiencies were significantly greater during 20-ft slot treatments as compared to 5-ft treatments in both spring and summer (Table

Table 5. Results from Wilcoxon Sign Rank Test comparing fish passage estimates and PSC performance metrics by slot treatment for spring and summer seasons. Significant differences are indicated by showing the nature of the relationship between 5- and 20-ft slot treatments. Numbers in parentheses are probability values (Pr>=| S |). The sample size (N) reflects the number of test blocks per season. Numbers passing into the PSC are based on in-turbine estimates during 5-ft treatments and on entrance estimates during 20-ft treatments.

Season	N	PSC Efficiency	PSC Effectiveness	Numbers Passing into PSC	Numbers Passing under PSC	Entrance Efficiency
spring	9	20 > 5 (0.004)	5 > 20 (0.020)	20 > 5 (0.004)	no diff.	20 > 5 (0.027)
summer	7	20 > 5 (0.031)	5 > 20 (0.016)	20 > 5 (0.016)	no diff.	20 > 5 (0.016)

5). Overall, spring and summer efficiencies were 84 and 75% for 20-ft slots and 69 and 71% for 5-ft slots. Estimates of fish numbers passing into the PSC were also significantly greater during 20-ft treatments than during 5-ft treatments in both seasons. We found no differences in total numbers of fish passing under the PSC between treatments in either season. There were no differences among treatments in numbers passing under the PSC by intake with the exception of Intake B in the summer when 20-ft treatments yielded significantly greater numbers (Pr>= 0.016) than 5-ft treatments. Effectiveness of the PSC was significantly greater during 5-ft treatments as compared to 20-ft treatments in spring and summer. Entrance efficiencies were significantly greater during 20-ft treatments than during 5-ft treatments in both seasons. Summertime comparisons between slot treatments were based on a sample size of 7 test blocks (instead of the original 10) because of a forced revision in treatment schedule after the crane used to switch slot-width opening broke down.

Effect of Lateral Distribution on FPE Estimates

Efficiencies of the PSC based on passage estimates from different combinations of within-intake transducer positions varied by 14% in the spring and 17% in the summer (Figure 18). The combination of north transducer-pairs per intake yielded the highest estimates of FPE for each season (76 and 74% for spring and summer, respectively). The lowest FPE estimates for each season (62% in spring and 57% in summer) resulted from using the south transducer-pairs per intake combination. The addition of spatial variance to the temporal

Spring

A		B		C		Efficiency
South	North	South	North	South	North	%
X		X		X		62
X		X			X	71
X			X	X		65
X			X		X	73
	X		X		X	76
	X		X	X		68
	X	X			X	74
	X	X		X		66
		Mean				69.4
		Median				69.5
		Confidence Level(95.0%)				4.1
		Range				14

Summer

A		B		C		Efficiency
South	North	South	North	South	North	%
X		X		X		57
X		X			X	73
X			X	X		59
X			X		X	73
	X		X		X	74
	X		X	X		60
	X	X			X	73
	X	X		X		59
		Mean				66.0
		Median				66.5
		Confidence Level(95.0%)				6.5
		Range				17

Figure 18. Fish passage efficiencies based upon different combinations of within-intake transducer locations during 5-ft slot treatments in spring (left) and summer. For each combination (row), one pair of transducers per intake (location of pair denoted by x) were used to calculate efficiency of the PSC. Mean, median, 95% confidence levels and range are listed.

variance produced 95 % confidence intervals that ranged from ± 4.8 to 7.4% for the spring and summer, respectively (Figure 19).

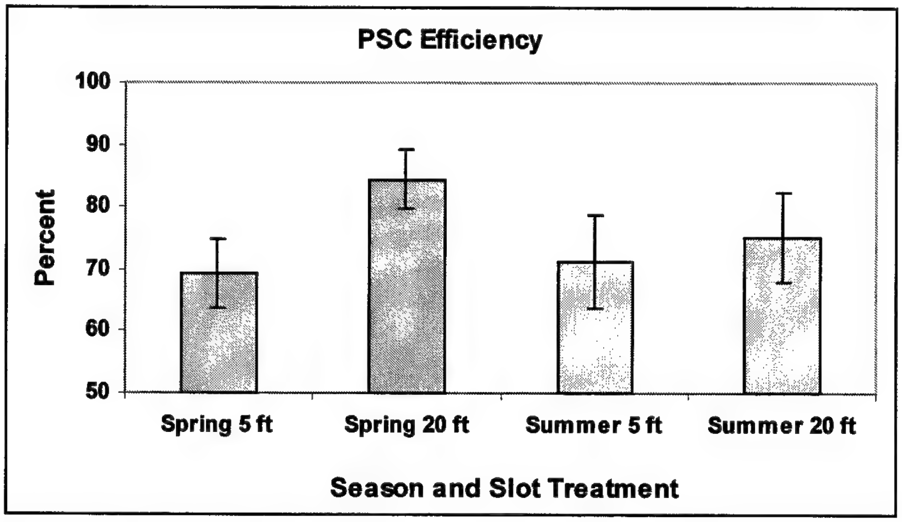

Figure 19. Bar chart showing prototype surface-collector efficiencies by season and slot-width treatment with 95 % confidence intervals based upon the sum of spatial and temporal variation.

Seasonal Trends

Fish passage efficiencies were generally highest in mid-spring for 5- and 20-ft slot treatments but fell off for both treatments at the end of May and the first week in June (Figure 20a). Twenty-ft slot treatment efficiencies during the summer began at about 60% but climbed through early July. Five-ft slot efficiencies decreased through the beginning of summer and then generally increased towards the latter part of the season. Besides a few peaks in the springtime, PSC effectiveness remained relatively stable through both spring and summer (Figure 20b). Guided fish passage during 5-ft treatments fluctuated slightly in the spring, with a peak occurring on 26 May (Figure 20c). Guided passage in the spring during 20-ft treatments peaked on 14 May and remained relatively high before decreasing towards the end of May. Guided fish passage in the summer followed similar trends across treatments, with lower numbers in the beginning of summer and gradually climbing to peaks in early July. Unguided passage generally increased during the study from spring through summer (Figure 20d) and was similar (except for two test blocks) for both treatments. Entrance efficiencies held similar seasonal patterns across treatments, with a slight dip through most of May and peaking at the end of spring before gradually declining through the summer (Figure 20e).

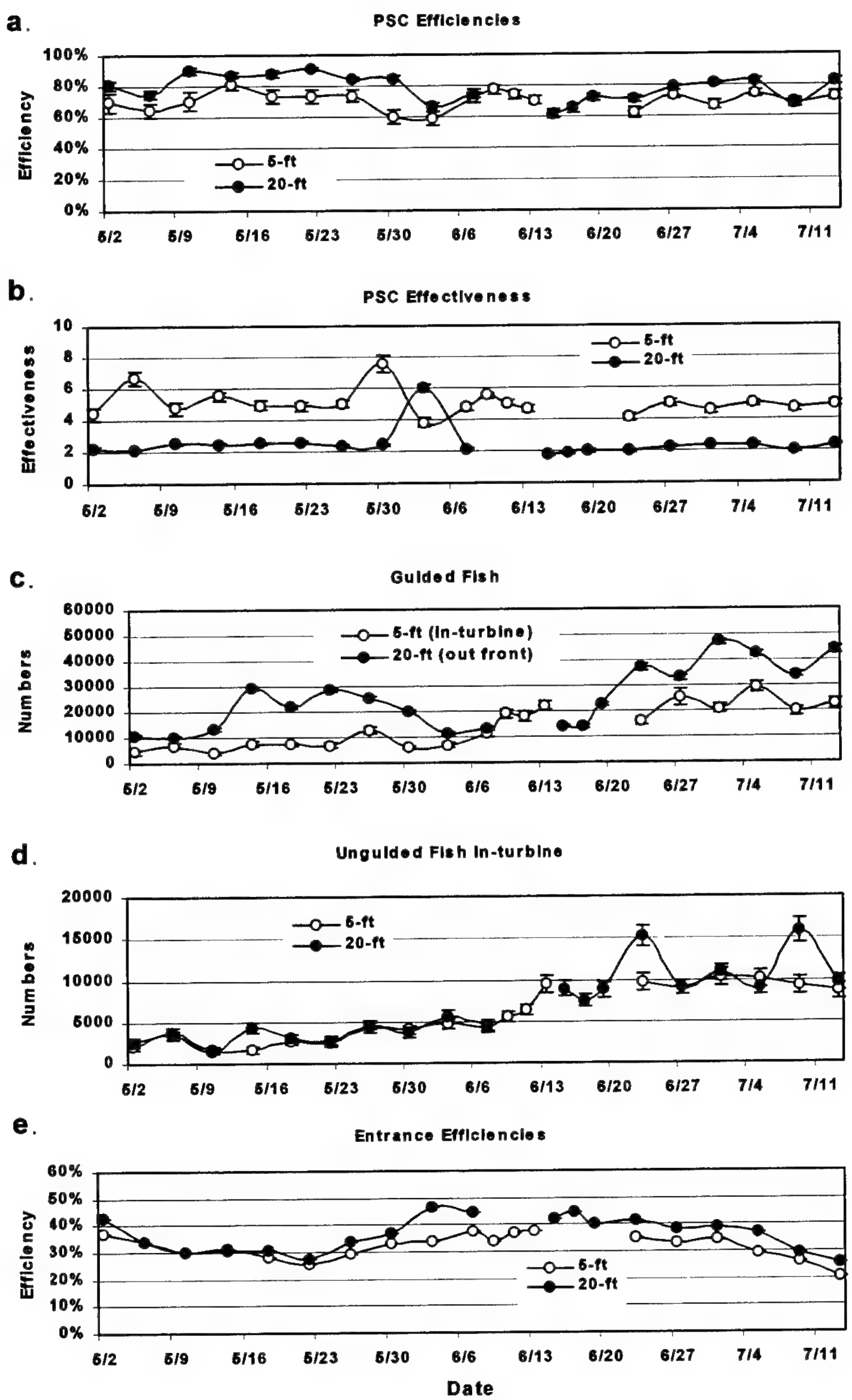

Figure 20. Seasonal trends in PSC efficiency (a), PSC effectiveness (b), guided fish (c), unguided fish (d) and entrance efficiency (e) by slot treatment. Error bars reflect 95% confidence limits. Spring is defined as the 2nd of May to the 4th of June and summer is defined as the 5th of June to the 14th of July.

Diel Trends

Efficiencies peaked in the early morning hours in the spring during 5-ft treatments but stayed relatively constant in the summer (Figure 21a). In contrast, 20-ft treatment efficiencies peaked in the early afternoon and bottomed out just

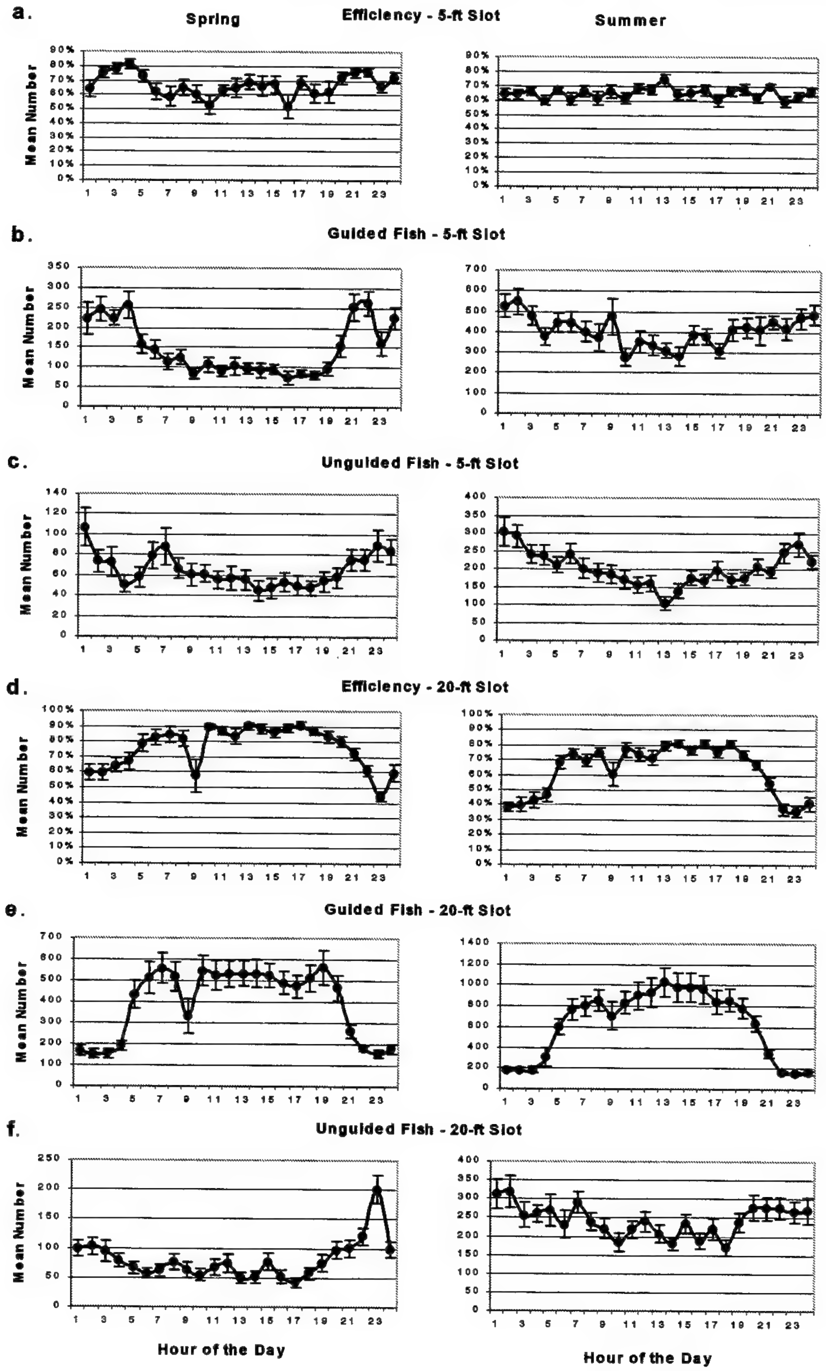

Figure 21. Diel trends of PSC efficiency, guided fish and unguided fish for 5-ft (a-c) and 20-ft (d-f) slot treatments for spring (left) and summer (right). Error bars are 95% confidence intervals about the mean.

before midnight in spring and summer (Figure 21d). Hourly patterns of guided fish during 5-ft treatments for spring and summer also contrasted with those from 20-ft treatments (Figure 21 b and e). In hours when passage peaked during the former treatment (late night and early morning), the latter treatment yielded fewer numbers. In hours when passage peaked during the 20-ft treatment (mostly daylight hours), passage during the 5-ft treatment was minimal. Unguided fish passage through the day was highest in late evening and early morning during 5-ft treatments in spring and summer (Figure 21c). For 20-ft slots, unguided fish passage peaked in the late evening in spring and early morning in summer (Figure 21f).

Discussion

Noise

Dense acoustic noise present during 20-ft slot treatments impaired our ability to identify fish traces in echograms from up-looking, in-turbine transducers, especially in the A and C intakes. Turbulence that entrained air at the entrance to and within the PSC circulated laterally into the A and C modules. Debris that accumulated on trash racks at the entrance to the PSC likely contributed to the amount of turbulence. Water in the A module of the PSC circulated counter clockwise while the water in the C module circulated clockwise. The eddies in the A and C modules were sustained by flow entering the 20-ft slot in the B module. Water circulation patterns caused entrained air to be concentrated in the upper water column by the time it passed into the A and C turbine intakes. Entrained air bubbles near the top of these intakes reflected sound and resulted in very noisy echograms that masked most fish traces. Water entering the middle of the 20-ft slot and B module did not circulate as much as water in the A and C modules before it passed into the center intake. Less circulation and sluiceway skimming of surface flow in the B module reduced the amount of entrained air in the center intake. Turbulence in the A and C slots was greater when Sluice Gate B was closed than when it was open. When closed, a hydraulic roller formed in the B module and surface water flowed upstream. Then middle portion of this upstream surface flow passed out of the PSC entrance, and sides rest collided with flows circulating in the A and C modules and created even more turbulence.

Fortunately, we were able to compare fish passage metrics among PSC slot treatments using in-turbine counts for 5-ft treatments and entrance counts for 20-ft treatments. Noise was not a problem during 5-ft treatments because the volume of water and associated turbulence passing through the PSC were both reduced. The strong correlation of in-turbine passage estimates during 5-ft slot treatments with entrance estimates based upon split-beam sampling suggests that the treatment comparison was reasonable.

Comparing In-turbine and Forebay Passage Estimates

Highly significant correlations of in-turbine estimates of fish that had passed through the PSC with estimates of numbers passing into PSC indicate that split-

beam sampling in the forebay can be used to estimate numbers of collected fish. In addition, a highly significant correlation of passage estimates from the middle pair of split beams with estimates from all three pairs (Figure 15) also suggests that a single pair of split beams would be adequate for sampling in 2000. Each pair should be randomly located in one of three possible lateral positions at every 20-ft slot.

In-turbine estimates were about 3.5 times higher than the forebay estimates for the 5-ft slot, which suggests that the acoustic screen model for expanding numbers of detected fish was not appropriate for the 5-ft slot opening. The acoustic screen model is an echo counting procedure used to estimate smolt passage rates at a transducer sample location. The acoustic screen can be visualized as a triangular plane on the axis of the acoustic beam, perpendicular to the direction of fish movement. The acoustic-screen model is used to spatially expand the number of fish based upon the ratio of the passage width to the beam diameter at the range of detection (Equation 1 under Materials and Methods).

The acoustic screen model is most appropriate when walls or piers bound the sample volume, flow is relatively straight through the opening, and fish distributions lateral to flow and across the beam are uniform. The 5- and 20-ft slots were not between piers, and the hydroacoustic beams had to be located upstream of the slots. For the 5-ft slot, a passage width corresponding to the diagonal distance from beam center to the edges of the slot better defines the dimension of the passage that could have been sampled than the 5-ft width (Figure 5). A wider 20-ft slot is more forgiving than a 5-ft slot for departures from the ideal acoustic-screen model. The 20-ft width divided by the diagonal distance from the center of the hydroacoustic beam to the edges of the entrance (22 ft) is closer to one (0.91) than a similar ratio for the 5-ft slot (5/11.9 ft = 0.42). Consequently, we believe that passage estimates for the 20-ft slot were less likely to have been biased than estimates for the 5-ft slot.

Estimates of numbers of fish passing under the PSC are best estimated by sampling with down-looking transducers in turbine intakes rather than upstream of the PSC. Fish sampled deep in the turbine intake are committed to passing and will only be counted once, unlike fish detected below the floor of the PSC 30-ft upstream of the turbine intake. Estimates of numbers passing beneath the upstream edge of the PSC floor were significantly higher than numbers passing at elevations < 30.5 ft inside the turbine.

Variation Among and Within Intakes

Differences among intakes suggest that it would be desirable (if practical) to sample every intake (18) within each of the six PSC units in 2000. Distribution of fish passage among intakes within a turbine unit is critical information for determining spatial coverage necessary for accurate sampling of PSC

performance in 2000. If passage is uniform across intakes, then spatial coverage could be effectively minimized without compromising the accuracy of the passage estimates. One intake per turbine unit could be sampled to estimate total turbine passage by applying an expansion factor of 3 to the single-intake estimates. We did not detect significant differences among intakes in spring during either slot treatment for unguided fish nor during 5-ft treatments for guided fish. However, we found significant differences in both guided and unguided passage among intakes in summer (see Table 3 and Figure 11).

The uniformity of spring passage distributions and the laterally skewed distributions in summer may result from differences in the swimming abilities of the yearling and sub-yearling fish. Yearling fish migrating in the spring are larger and more developed physiologically than the sub-yearling summer migrants and presumably can maintain their lateral position more effectively than the summer migrants despite circular flows in the A and C modules. In contrast, sub-yearling fish are more likely than yearling fish to be entrained in eddies.

Lateral distribution of fish passage within intakes is another critical element to consider for determining sampling effort for the evaluation in 2000. If fish were uniformly distributed across the intake, a single transducer placed anywhere in an intake would provide adequate coverage for accurately estimating passage. However, lateral distributions of passage within intakes were seldom uniform in 1999 (see Table 4 and Figure 11).

The consequences of non-uniform distributions among and within intakes not only relate to spatial sampling effort but also to the precision of measurements of PSC performance. The PSC passage efficiencies varied considerably depending upon the selection of transducer locations (see Figure 18). The 1999 data indicate that spatial variation among and within intakes accounted for more than 80% of the confidence limits based upon spatial and temporal variation in efficiency estimates. Guided and unguided passage estimates within an intake were sometimes skewed in opposite directions (see Table 4: Intake C in spring and summer) or one term was skewed while the other was uniform (Table 4: Intake A). In terms of efficiency, for example, if the south pair of transducers per intake were chosen to estimate FPE, the resultant efficiencies would be 62 and 57% in the spring and summer, respectively. These ratios are low compared to efficiencies based on the north pair of transducers per intake (76% in spring and 74% in summer).

Allocation of sampling effort for the Year 2000 study should attempt to sample sources of higher variation first, inasmuch as sampling each of 18 intakes and two lateral locations per intake would not be cost effective. The variation among intakes usually was higher than the variation within intakes so the most effective approach would be to sample all intakes first, if possible. Next, multiple positions within the turbine unit with the highest variance, as determined by preliminary sampling, could be sampled, if resources permit. This would provide some measure of within-intake variance that could be expanded and

incorporated into precision estimates for PSC efficiency. The 1999 data suggest that 95% confidence limits may be ±4-7% higher than expected from temporal sampling alone.

Vertical Distributions

Vertical distributions of fish in the forebay immediately upstream of the 5- and 20-ft slots in the PSC were significantly different (Figures 16 and 17). Numbers and proportions of fish at different depths provide a different view of slot-width effects. Significantly higher numbers of fish immediately upstream of the 20-ft slot than upstream of the 5-ft slot suggests that the wider slot attracts more fish to the vicinity of the entrance than the narrow slot. Cumulative frequencies indicate that proportionally more fish pass under the 5-ft slot than pass under the 20-ft slot. Mobile hydroacoustic data from 1996 (Ploskey et al. 1998) indicated that that 80% of the fish within 80 ft of the powerhouse were within 40 ft of the surface of the water. Split-beam data at the face of the PSC (about 30 ft upstream of the powerhouse) generally agree with that assessment. If vertical distributions change as fish approach the powerhouse, it must occur closer than 30 ft from the powerhouse.

In-turbine vertical distributions of fish were deeper than forebay distributions and not just because the turbine-intake ceiling forces water to greater depths. Proportions detected below the floor of the 5-ft slot and inside the turbine (29-31 %) were higher than the proportions below the elevation of the floor upstream of the PSC (18-20 %). This suggests that vertical distributions change significantly between the time that fish contact the PSC and the time they are detected in the turbine downstream.

PSC Evaluation

Differences Between Slot Treatments

Although we found no significant differences between the two treatments for estimates of fish passing under the PSC in spring or summer, the PSC collected significantly more fish during 20-ft treatments than during 5-ft treatments. Entrance and slot efficiencies also were significantly higher for the 20- than for the 5-ft treatment. Only PSC effectiveness was higher with the 5-ft treatment, which passed 1780 cfs less water than the 20-ft treatment.

We were not surprised that more fish were collected in the higher water volumes entering the 20-ft wide slot relative to the 5-ft slot, but higher efficiencies without differences in numbers passing under the PSC raise another question. Where did the additional fish come from? It must be that the larger flow net produced by the 20 ft slot provides orientation cues to fish at greater

distances than does the less extensive flow net generated by the 5-ft slot. The vertical distribution of fish estimated from split-beam transducers in front of the PSC had many more fish near the 20- than the 5-ft slot in both spring and summer (Figures 15 and 16). Entrance efficiency estimates, although they may be compromised by multiple counting, also were higher for the 20 ft opening. If those results are valid, they may indicate that something about the conditions at the wider opening are more conducive to fish entry than at the 5-ft opening.

Seasonal Trends

Numbers of guided and unguided fish increased from spring through summer but PSC efficiency and effectiveness had only slight seasonal trends. Summer efficiencies were only slightly lower than spring efficiencies, which is consistent with earlier results, but efficiency did not drop as precipitously as those associated with in-turbine screens (Ploskey et al. In Press). It is likely that summer migrants, being smaller and younger than the spring migrants, were less able to resist the downward flows near the turbine intakes. However, sampling immediately upstream of the PSC showed no obvious difference in vertical distributions from spring to summer (Figures 16 and 17).

Whereas there may be seasonal differences in fish behavior that might influence entrance efficiency, the lowest efficiencies in late summer likely were caused by the presence of spent American shad wallowing in split-beam sample volumes. Entrance efficiencies for both treatments (Figure 20e) showed some seasonal trends in spring but clearly were lowest at the end of summer. We filtered our data to remove fish traces with mean target strengths greater than –45 dB re 1 μPa at 1 m. Fish of this acoustic size would be too large to be sub-yearling salmon, but many American shad may appear acoustically smaller than –45 dB so the filtering was not completely effective. After the season, we managed to collect target strength data on one 419-mm long American shad from the Powerhouse smolt monitoring facility. We found that animal to had target strengths as low as –55 dB when ensonified in ventral aspect, which is similar to minimum target strengths of sub-yearling salmon passing through the up-looking split beams at the PSC. This was surprising since the adult shad are many times larger than the summer smolts. If that one fish was representative of adult American shad, then our sampling must have included some sizable proportion of them after mid June. Their wallowing in and out of the sampling volume would reduce entrance efficiencies by increasing the denominator of the index by multiple counting. The American shad migration through the Bonneville fish ladders began in late May and peaked the third week in June.

Diel Trends

The 20-ft treatment apparently altered the diel pattern of passage for fish collected by the PSC and the efficiency of the collector. Passage of guided fish during the 5-ft-slot treatment and unguided fish (either treatment) was higher at

night than during the day, which is typical of juvenile salmon passage through turbines without a surface collector (Figure 21, c and f). In contrast, guided fish passed more during daytime than at night during the 20-ft treatment (Figure 21, e), which is the typical pattern for surface passage at a sluiceway. Similarly, passage efficiency had little diel pattern under the 5-ft slot treatment, but increased significantly during the daytime under the 20-ft treatment (Figure 21). The 20-ft slot efficiency rose steeply before dawn and stayed high until it began to drop at about 1900 hours to a daily low at 2300 hours. The 5-ft slot not only was less successful at collecting fish than the 20-ft slot, but it also collected fish on a very different schedule, similar to deep passage at a turbine. Perhaps smolts that passed through the 5 ft opening often did so when they lost visual orientation. That hypothesis is consistent with the sharp drop in "guided" 5 ft passage at about 0400 and the rise that begins at 2000 hrs. (Figure 21).

Comparison to 1998 Results

In-turbine data collected in spring 1999 with up-looking transducers during the 5-ft slot treatments suggest that our 1998 assumption that 25 % of the collected fish passed within 8 ft of the intake ceiling was appropriate. In 1998, we increased the estimates of PSC passage by a factor of 1.33 assuming that we sampled 75% of the intake area above the PSC floor and a like percentage of the fish. Multiplying by 1.33 increased fish passage estimates to represent passage for the whole intake. The upper 8 ft of range at 33° off vertical corresponds to > 32 ft in elevation (Figure 10). These vertical distribution data indicate that 27.4 and 32.9 % of the fish passed within 8 ft of the intake ceiling, and these percentages are close to the 25 % we assumed in 1998.

Nevertheless, 1999 estimates of PSC efficiency for Unit 5 were lower than the mean estimated for units 3 and 5 in 1998 (Table 6), a result that also was observed for radio tagged fish (Noah Adams; Personal Communications). The 3.4 % drop in efficiency for the 20-ft slot in spring was not significant, but the other estimates were significantly lower in 1999 than in 1998. The reason for the difference between the years is unknown. However, Unit 5 median discharge was higher in 1999 (median = 11, 291 cfs) than in 1998 (median = 10,100 cfs), except during the last treatment block (Figure 22). Efficiencies during the last test block did not differ much from those observed during earlier blocks but comparing efficiencies for one block to all others is far from conclusive.

Table 6. Comparison of PSC slot efficiencies in 1998 and 1999.

Season	Slot Treatment (ft)	1998	1999	Difference 1999-1998
Spring	5	92.2	69.3	-22.9
	20	87.8	84.4	-3.4
Summer	5	84	71.3	-12.7
	20	92	75.2	-16.8

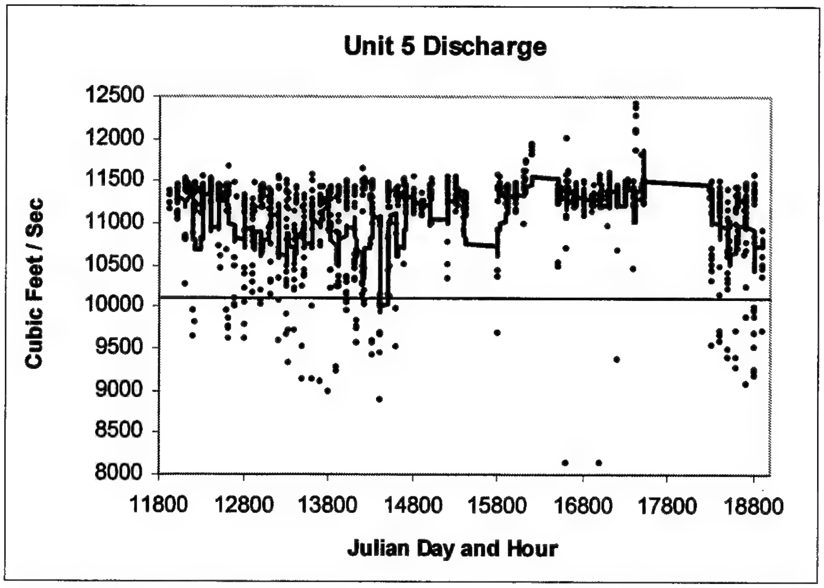

Figure 22. Seasonal trends in discharge of Turbine Unit 5 in 1999. The horizontal line is the mean discharge in 1998 and the other line is a 24-hour moving average for hourly points in the chart.

The effectiveness of the PSC also was lower in 1999 than in 1998 for the 5-ft slot treatment in spring and for the 5- and 20-ft slot treatments in summer (Table 7). The difference in 20-ft treatments in spring was not significant at $\alpha = 0.05$ (P = 0.155) because one of the nine estimates was higher (2.18 times) in 1999 than in 1998. Again, the only operational difference between the two years was a 12 % increase in unit discharge in 1999 over 1998.

Table 7. Comparison of 1998 and 1999 estimates of fish passage effectiveness.

SEASON	PSC OPENING (ft)	PSC Effectiveness 1998	1999	Difference 1999-1998
SPRING	5	9.7	5.1	-4.6
SPRING	20	3.4	2.6	-0.8
SUMMER	5	8.1	4.8	-3.3
SUMMER	20	3.2	2.1	-1.1

Inter-tracker bias

Inter-tracker bias was not a major concern in this one unit study because one person processed over 80% of the data, and we were careful to have each tracker process whole blocks of two treatments when both were working. Nevertheless,

we been evaluating the potential for systematic bias due to differences in human tracker performance (Ploskey et al. In press, Ploskey et al., In Review). Johnson et al. (In Review) also began examining inter- and intra-tracker bias. We consider these differences in hydroacoustic counts among and within trackers to be a potentially important source of bias that sometimes has been ignored in hydroacoustic studies. In 1999 at The Dalles, Ploskey et al. (In Review) found very close agreement among trackers that were trained intensively together when they redundantly tracked many hours of clean data (low acoustic noise). However, counts were more variable among trackers processing sluiceway data and even more variable for spillway data. Inter-tracker variation increased in proportion to the amount of acoustic noise in echograms. Inasmuch as echograms for the PSC at Bonneville Powerhouse 1 have noise characteristics comparable to The Dalles sluiceway, inter-tracker bias is a concern. The easiest way to control inter-tracker bias, which tends to be cumulative over time, is to use the same trackers throughout the season and distribute samples so that the average hourly counts incorporate inter-tracker variation. If automated tracking software is used, it must be calibrated against the average human tracker and checked by regressing human tracker counts on autotracker counts for hourly samples taken throughout the sampling season. Autotracking software does not have intra-tracker bias from factors that may affect people (e.g., fatigue), but autotracking counts may change if the noise regime changes.

Non-target Species

The most common problem with counting non-target species is associated with the appearance of spent adult American shad in late summer, which we will continue to evaluate. As early as possible next year (shad appear in the ladders in late May) we will collect live American shad and do target strength studies on them. Our goal is to obtain valid data sets on as many as 20 adult fish and to capture the size range of the fish we are likely to encounter. From those data we will be able to accurately determine the appropriate target strength filter for summer data to exclude shad. If it turns out that the one fish for which we have target strength data is representative, then target strength filtering will not suffice. We are planning to use a separate sound-production system producing pulses around 120 kHz to exclude the shad from sampling volumes at one PSC unit. Such sound is well established as a tool to move Alosine shads and is being used in fish protection at power plants elsewhere (Nestler et al. 1992, Dunning et al. 1992). The effectiveness of that system will be experimentally evaluated next year, and those results should help define the scope of the problem.

Recommendations

1. The 20-ft PSC slot should be the primary focus of research in 2000 because it outperformed the 5-ft slot in attracting and collecting fish and had a significantly higher efficiency than the 5-ft slot.

2. Sampling with down-looking transducers in turbine intakes downstream of the PSC should be continued to estimate passage of fish under the PSC. Counts of fish in the upper portion of these down-looking beams also will provide a calibration check on estimates of passage through the PSC by split-beam transducers deployed at the slot entrances.

3. If resources are sufficient, every PSC intake at Units 1-6 should be sampled in 2000 by randomly locating a single down-looking transducer in one of three possible positions (right, center, left) in each intake. In addition, three intakes of one unit, preferably the unit with the highest variance as determined by preliminary sampling, could be sampled with two or more transducers to quantify this spatial component of variance.

4. At least one pair of up- and down-looking split-beam transducers should be deployed at every PSC entrance to estimate numbers of fish entering the PSC and the vertical distribution of passage. These data also will provide supplement behavioral information.

5. Inter-tracker bias should be controlled by using the same trackers throughout the season and distributing samples among trackers so that average hourly counts have the same bias. Trackers should not be assigned to one system or set of transducers.

6. An ultrasonic repulsion system for American shad should be installed upstream of the PSC unit that will be most intensively sampled with split-beam transducers and the multibeam sonar to reduce intrusion and bias in summer estimate. The system should be evaluated to quantify the scope of the problem and benefits of repelling these non-target species in summer.

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Appendix A: Synopsis of the Statistical Analyses Associated with the 1999 Bonneville Dam Hydroacoustic Studies

By

John R. Skalski
Columbia Basin Research
School of Fisheries
University of Washington
1325 Fourth Avenue, Suite 1820
Seattle, WA 98101-2509

I. Table of Contents

II. Introduction

The purpose of this report is to describe statistical methods associated with the 1999 Bonneville Dam hydroacoustic studies at Powerhouse #1. The study will consist of two seasons as follows:

Spring Study: 21 April – 31 May 1999

Summer Study: 6 June – 15 July 1999

Placement of transducers and statistical analyses will be the same for both seasons. The hydroacoustic study has two primary objectives; these are:

1. Evaluate hydroacoustic approaches to estimating passage efficiencies in preparation for a year 2000 test.

2. Compare passage efficiencies at the prototype surface collector (PSC) under two different slot widths of 5 ft and 20 ft.

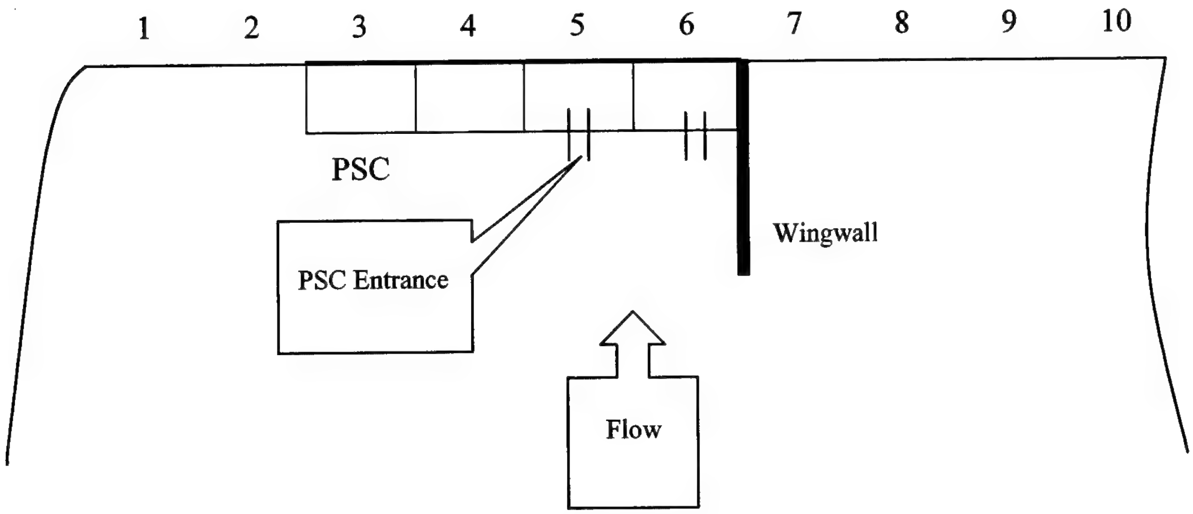
The first of these objectives is to fine tune the monitoring and evaluation (M&E) techniques that will ultimately be used in a full-scale surface collector test in the year 2000. The second objective is to assess PSC passage efficiency and effectiveness under two different slot configurations.

The statistical plans presented in this report will be reviewed by the US Army Corps of Engineers (USACE), study personnel, and the *ad hoc* statistical committee prior to the study.

III. Deployment of Hydroacoustic Transducers

The prototype surface collector will be located in front of turbine units 3-6 at Powerhouse #1 (Figure 1). There will not be PSC entrances in front of Unit #3 in 1999. Unit #4 will be off-line during 1999, so the PSC there will be closed. Units #5 and #6

Figure 1. Schematic of PSC located in front of Powerhouse #1 at Bonneville Dam.



will each have an entrance slot which will vary in width (i.e., 5 or 20 ft) over time according to the experimental plan.

A. PSC Entrance

No transducers will be positioned in the PSC entrance in front of turbine Unit #6. The PSC entrance at Unit #5 will consist of 3 uplooking and 3 downlooking split-beam transducers (Figure 2a). Ten 2-minute samples will be systematically collected from each of 3 pairs of transducers upstream of the PSC entrance at Unit #5 every hour. Each pair will consist of 2 vertically aligned up- and downlooking transducers that will be sampled simultaneously by alternating pings between the transducers.

B. Unit #5

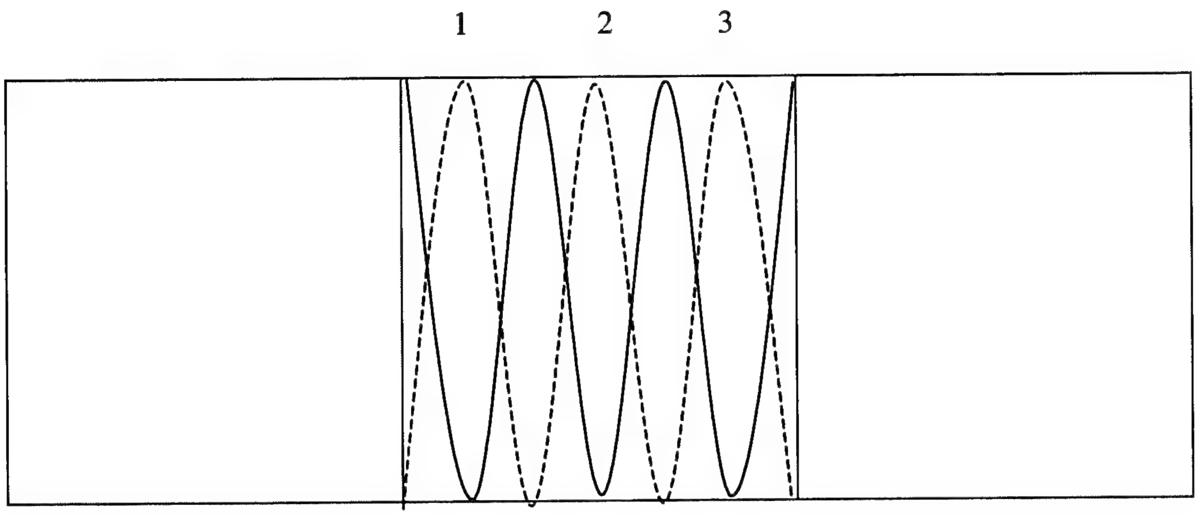
At each of the 3 intake slots of Unit #5, 2 uplooking and 2 downlooking single-beam transducers will be positioned (Figure 2b). The upper and wider half of the beam from the uplooking turbine transducers will be used to enumerate numbers of smolt passing through the PSC. The lower and wider half of the beam from the downlooking transducers will be used to enumerate numbers of smolt passing under the PSC (Figure 3). Five 2-minute samples will be systematically collected from each of 6 pairs of transducers in Unit #5 every hour. Each pair will consist of 2 vertically aligned up- and downlooking transducers that will be sampled simultaneously by alternating pings between the transducers.

C. Unit #6

There will be one pair of uplooking and downlooking single-beam transducers per turbine slot in Unit #6 (Figure 4). Again, the lower half of the downlooking transducers will be used to enumerate numbers of smolt passing through the PSC. The upper half of the uplooking transducers will be used to enumerate numbers of smolt passing under the PSC. Ten 2-minute samples will be systematically collected from each of 3 pairs of transducers in Unit #6 every hour. Each pair will consist of 2 vertically aligned up- and

Figure 2. Schematic of transducer locations at (a) the PSC entrance and (b) turbine intakes of Unit #5.

a. PSC entrance



b. Turbine intakes

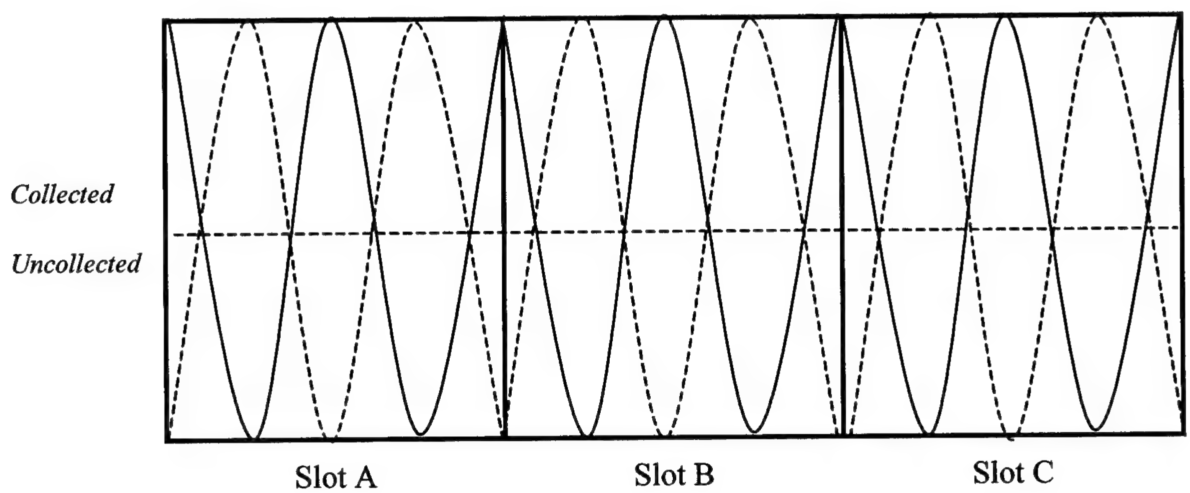


Figure 3. Side view of fixed-location hydroacoustic beams at turbine Unit #5 at Bonneville Powerhouse #1. Guided and unguided fish locations within turbine slot are denoted.

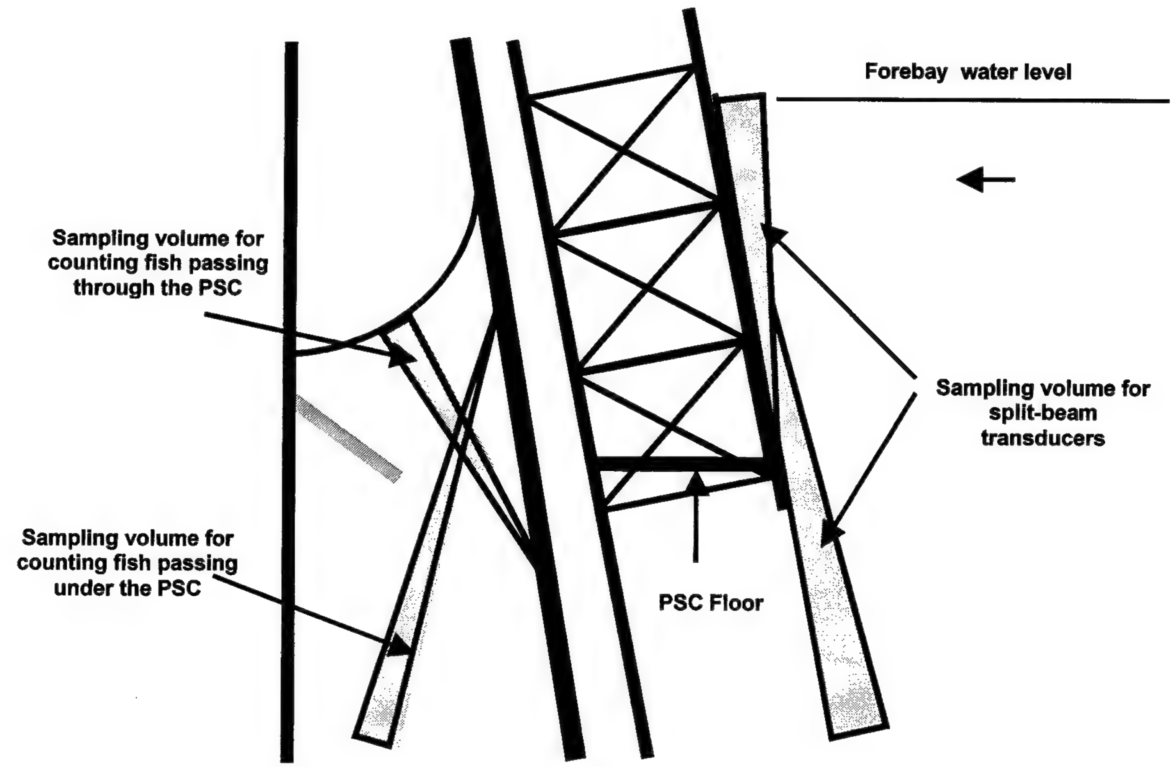
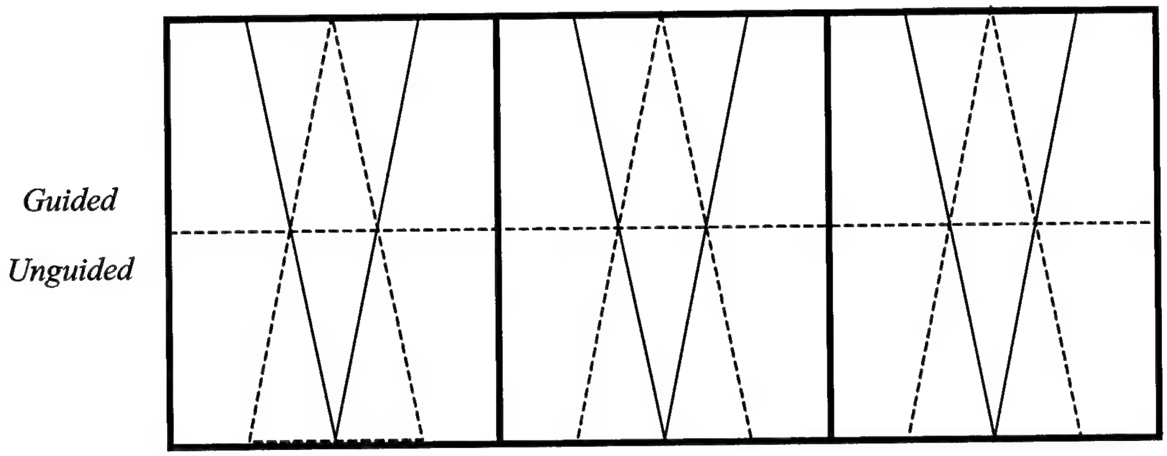


Figure 4. Schematic of uplooking and downlooking single-beam transducers in intake slots of turbine Unit #6 at Powerhouse #1 at Bonneville Dam.



downlooking transducers that will be sampled simultaneously by alternating pings between the transducers.

IV. Estimating PSC Performance

The 1999 hydroacoustic study will evaluate the performance of the PSC in guiding smolt. The performance will be evaluated using three performance measures defined as follows:

1. PSC collector efficiency

$$PSCE = \frac{C}{C+D}$$

where C = number of smolt passing through the PSC,

D = number of smolt passing under the PSC.

2. PSC effectiveness

$$PSCF = \frac{C/F_P}{(C+D)/(F_P+F_T)}$$

where F_P = flow volume going through the PSC entrance,

F_T = flow volume going into the turbine unit(s).

3. PSC entrance efficiency

$$PSCEE = \frac{Z_{IN}}{Z_{IN}+Z_{OUT}}$$

where Z_{IN} = number of smolt detected moving into the PSC by split-beam transducers at the PSC entrance,

Z_{OUT} = number of smolt detected moving away from the PSC entrance by split-beam transducers.

Entrance efficiency characterizes the near-field potential for a smolt entering the PSC, given it is at the PSC entrance. Entrance efficiency will be estimated from data collected by the split-beam transducers at the PSC entrance at Unit #5. Data collected by the single-beam transducers in turbine intakes of Units #5 (Figure 3) and #6 (Figure 4) will form the basis for the estimates of PSC efficiency and effectiveness.

A. Unit #5 Passage

Estimating Collected Numbers. Using the two uplooking single-beam transducers per turbine slot, an estimate of total collected smolt in Unit #5 can be estimated according to the formula

$$\hat{C}_5 = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\sum_{l=1}^{2}\frac{M}{m}\sum_{g=1}^{m} v_{ijklg}$$

where v_{ijklg} = weighted number of smolt in the gth sampling interval $(g = 1,\ldots,m)$ at the lth transducer location $(l = 1, 2)$ in the kth intake slot $(k = 1,\ldots,3)$ in the jth hour $(j = 1,\ldots,23)$ of the ith day $(i = 1,\ldots,d)$.

Here, v_{ijklg} is the expanded number of detections of smolt in a 2-minute time interval within the ½ cross-sectional area of the turbine intake slot. Nominally, m = 5 sampling intervals per location per hour from among M = 30.

Treating each half of a turbine intake slot as a separate spatial stratum, the variance of $\hat{C}_5$ can be computed as follows:

$$V\hat{a}r\left(\hat{C}_5\right) = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\sum_{l=1}^{2}\left[\frac{M^2\left(1-\frac{m}{M}\right)\hat{S}^2_{v_{ijkl}}}{m}\right]$$

and where

$$\hat{S}^2_{v_{ijkl}} = \frac{\sum_{g=1}^{m}\left(v_{ijklg} - \overline{v_{ijkl}}\right)^2}{(m-1)}$$

$$\overline{v_{ijkl}} = \frac{\sum_{g=1}^{m} v_{ijklg}}{m}.$$

<u>Estimating Uncollected Numbers.</u> Using the two downlooking single-beam transducers per turbine slot, an estimate of total uncollected smolt can be estimated according to the formula

$$\hat{D}_5 = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\sum_{l=1}^{2}\frac{N}{n}\sum_{g=1}^{n} w_{ijklg}$$

where w_{ijklg} = weighted number of smolt in the gth sampling interval $(g = 1, \ldots, n)$ at the lth transducer location $(l = 1, 2)$ in the kth intake slot $(k = 1, \ldots, 3)$ in the jth hour $(j = 1, \ldots, 23)$ of the ith day $(i = 1, \ldots, d)$.

The value w_{ijklg} is the expanded number of detections of smolt in a 2-minute time interval within the ½ cross-sectional area of a turbine intake slot. Nominally, $n = 5$ sampling interval per location per hour from among $N = 30$.

Treating again each half of a turbine intake slot as a separate spatial location, the variance of $\hat{D}_5$ can be computed as follows:

$$V\hat{a}r\left(\hat{D}_5\right) = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\sum_{l=1}^{2}\left[\frac{N^2\left(1-\frac{n}{N}\right)\hat{S}^2_{w_{ijkl}}}{n}\right]$$

where

$$\hat{S}^2_{w_{ijkl}} = \frac{\sum_{g=1}^{n}\left(w_{ijklg} - \overline{w_{ijkl}}\right)^2}{(n-1)}$$

$$\overline{w_{ijkl}} = \frac{\sum_{g=1}^{n} w_{ijklg}}{n}.$$

B. Unit #6

<u>Estimating Collected Numbers.</u> Using the single uplooking single-beam transducer per turbine slot, an estimate of total collected smolt in Unit #6 can be estimated according to the formula

$$\hat{C}_6 = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\frac{M}{m}\sum_{g=1}^{m} v_{ijkg}$$

where v_{ijkg} = weighted number of smolt in the gth sampling interval $(g = 1, \ldots, m)$ in the kth intake slot $(k = 1,\ldots,3)$ of the jth hour $(j = 1,\ldots,23)$ of the ith day $(i = 1, \ldots, d)$.

The value v_{ijkg} is the expanded number of detections of smolt in a 2-minute time interval for a turbine intake slot. Nominally, m = 10 sample intervals per hour from among M = 30.

Treating each "intake-hour" as a stratum, the variance of $\hat{C}_6$ can be computed as

$$\hat{Var}\left(\hat{C}_6\right) = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\left[\frac{M^2\left(1-\frac{m}{M}\right)\hat{S}^2_{v_{ijk}}}{m}\right]$$

and where

$$\hat{S}_{v_{ijk}} = \frac{\sum_{g=1}^{m}\left(v_{ijkg} - \overline{v_{ijk}}\right)^2}{(m-1)}$$

$$\overline{v_{ijk}} = \frac{\sum_{g=1}^{m} v_{ijkg}}{m}.$$

<u>Estimating Uncollected Numbers.</u> Using the single downlooking single-beam transducer per turbine intake, an estimate of total uncollected smolt in Unit #6 can be estimated according to the formula

$$\hat{D}_6 = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\frac{N}{n}\sum_{g=1}^{n} w_{ijkg}$$

where w_{ijkg} = weighted number of smolt in the gth sampling interval $(g = 1, \ldots, m)$ in the kth intake slot $(k = 1, \ldots, 3)$ of the jth hour $(j = 1, \ldots, 23)$ of the ith day $(i = 1, \ldots, d)$.

The value w_{ijkg} is the expanded number of detections of smolt in a 2-minute time interval for a turbine intake slot. Nominally, n = 10 sample intervals per hour from among N = 30.

Treating each "intake-hour" as a stratum, the variance of $\hat{D}_6$ can be computed as

$$V\hat{a}r\left(\hat{D}_6\right) = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{3}\left[\frac{N^2\left(1-\frac{n}{N}\right)\hat{S}^2_{w_{ijk}}}{n}\right]$$

where

$$\hat{S}_{w_{ijk}} = \frac{\sum_{g=1}^{n}\left(w_{ijkg} - \overline{w_{ijk}}\right)^2}{(n-1)}$$

$$\overline{w_{ijk}} = \frac{\sum_{g=1}^{n} w_{ijkg}}{n}.$$

C. Estimating Total Turbine Passage at Unit #5

The most direct means of estimating total turbine passage is to sum the collected $\left(\hat{C}_5\right)$ and uncollected $\left(\hat{D}_5\right)$ counts where

$$\hat{X}_5 = \hat{C}_5 + \hat{D}_5.$$

In this case,

$$V\hat{a}r\left(\hat{X}_5\right) = V\hat{a}r\left(\hat{C}_5\right) + V\hat{a}r\left(\hat{D}_5\right).$$

D. Estimating Total Turbine Passage at Unit #6

Again, the most direct means of estimating total turbine passage is to sum the guided $\left(\hat{C}_6\right)$ and unguided $\left(\hat{D}_6\right)$ estimates where

$$\hat{X}_6 = \hat{C}_6 + \hat{D}_6$$

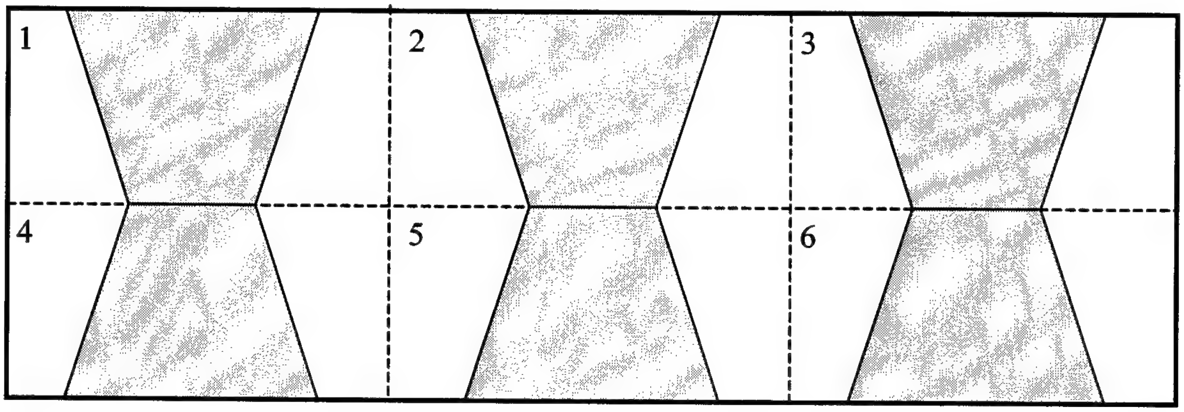
with associated variance

$$V\hat{a}r\left(\hat{X}_6\right) = V\hat{a}r\left(\hat{C}_6\right) + V\hat{a}r\left(\hat{D}_6\right).$$

E. Estimating PSC Passage at Unit #5

The PSC entrance at Unit #5 will have 3 downlooking and 3 uplooking split-beam transducers to estimate smolt passage. Using the maximum beam diameters of the up-

and downlooking transducers at the top and bottom of the PSC entrance produces six spatial strata as depicted below:



An estimate of total smolt passage through the PSC entrance can be calculated as follows

$$\hat{A} = \sum_{i=1}^{d} \sum_{j=1}^{23} \sum_{k=1}^{6} \frac{L}{l} \sum_{g=1}^{l} u_{ijkg}$$

where u_{ijkg} = weighted number of smolt in the gth sampling interval $(g = 1, \ldots, l)$ at the kth spatial stratum $(k = 1, \ldots, 6)$ in the jth hour $(j = 1, \ldots, 23)$ of the ith day $(i = 1, \ldots, d)$.

Here u_{ijkg} is the expanded number of detections of smolt in a 2-minute time interval in one of the six spatial subareas of the PSC entrance. Nominally, l = 10 sampling intervals per location per hour from among L = 30.

Treating each of the six entrance subareas as strata, the variance of $\hat{A}$ can be computed as follows:

$$V\hat{a}r\left(\hat{A}\right) = \sum_{i=1}^{d} \sum_{j=1}^{23} \sum_{k=1}^{6} \left[\frac{L^2 \left(1 - \frac{l}{L}\right) \hat{S}^2_{u_{ijk}}}{l} \right]$$

and where

$$\hat{S}^2_{u_{ijk}} = \frac{\sum_{g=1}^{l}\left(u_{ijkg} - \overline{u_{ijk}}\right)^2}{(l-1)}$$

$$u_{ijk} = \frac{\sum_{g=1}^{l} u_{ijkg}}{g}.$$

These formulas pertain to estimating smolt passage into the PSC with the 20-ft opening. When the 5-ft opening is in operation, only the middle set of up- and downlooking transducers will be used to estimate smolt passage. In this case, there will be only two spatial subareas (i.e., zones 2 and 5), and as such, k will index $k = 1,2$ in the above formulas for $\hat{A}$ and $V\hat{a}r\left(\hat{A}\right)$.

F. Estimates of Performance Measures

The estimator of PSC efficiency for Unit #5 would be calculated as

$$P\hat{S}CE_5 = \frac{\hat{C}_5}{\hat{C}_5 + \hat{D}_5}$$

with associated variance estimator

$$V\hat{a}r\left(P\hat{S}CE_5\right) = P\hat{S}CE_5^2\left(1 - P\hat{S}CE_5\right)^2\left[CV\left(\hat{C}_5\right)^2 + CV\left(\hat{D}_5\right)^2\right]$$

and where $\hat{C}V$ is expressed as

$$\hat{C}V\left(\hat{\theta}\right) = \frac{\sqrt{V\hat{a}r\left(\hat{\theta}\right)}}{\hat{\theta}}$$

for any estimator $\hat{\theta}$. The estimate of PSC efficiency for Unit #6 would be computed analogously.

The estimator of PSC combined efficiency across Units #5 and #6 would be computed as

$$\hat{PSCE}_{5-6} = \frac{\hat{C}_5 + \hat{C}_6}{\hat{C}_5 + \hat{C}_6 + \hat{D}_5 + \hat{D}_6}$$

with associated variance estimator

$$\hat{Var}\left(\hat{PSCE}_{5-6}\right) = \hat{PSCE}^2_{5-6}\left(1 - \hat{PSCE}_{5-6}\right)^2 \cdot \left[\frac{Var\left(\hat{C}_5\right) + Var\left(\hat{C}_6\right)}{\left(\hat{C}_5 + \hat{C}_6\right)^2} + \frac{Var\left(\hat{D}_5\right) + Var\left(\hat{D}_6\right)}{\left(\hat{D}_5 + \hat{D}_6\right)^2}\right].$$

The estimator of PSC effectiveness for Unit #5 would be calculated as

$$\hat{PSCF}_5 = \frac{\hat{C}_5 / F_{P5}}{\left(\hat{C}_5 + \hat{D}_5\right)/\left(F_{P5} + F_{T5}\right)}$$

with associated variance estimator

$$\hat{Var}\left(\hat{PSCF}_5\right) = \left(\frac{F_{P5} + F_{T5}}{F_{P5}}\right)^2 \cdot \hat{Var}\left(\hat{PSCE}_5\right)$$

and where F_{P5} = flow volume through PSC entrance above Unit #5,

F_{T5} = flow volume entering Unit #5.

The estimator of $PSCF_6$ and associated variance would be calculated analogously.

Total PSC effectiveness across Units #5 and #6 would be calculated as

$$\begin{aligned}\hat{PSCF}_{5-6} &= \frac{\left(\hat{C}_5 + \hat{C}_6\right)/\left(F_{P5} + F_{P6}\right)}{\left(\hat{C}_5 + \hat{C}_6 + \hat{D}_5 + \hat{D}_6\right)/\left(F_{P5} + F_{P6} + F_{T5} + F_{T6}\right)} \\ &= \hat{PSCE}_{5-6} \cdot \left(\frac{F_{P5} + F_{P6} + F_{T5} + F_{T6}}{F_{P5} + F_{P6}}\right)\end{aligned}$$

with associated variance estimator

$$V\hat{a}r\left(P\hat{S}CF_{5-6}\right)=\left(\frac{F_{P5}+F_{P6}+F_{T5}+F_{T6}}{F_{P5}+F_{P6}}\right)^2\cdot V\hat{a}r\left(P\hat{S}CE_{5-6}\right).$$

with associated variance estimator.

G. Estimating PSC Entrance Efficiency

Estimating PSC entrance efficiency (PSCEE) is different from other performance measures in that the data are taken from individual fish traces using the split-beam transducers. Three-dimensional criteria will need to be established that define a fish as either entering the PSC or moving elsewhere. Using the six spatial strata defined by the 3 pairs of up- and downlooking transducers, counts of smolt passing through the PSC (Z_{IN}) and moving away from the PSC (Z_{OUT}) can be estimated.

The total number of guided smolt will be estimated by

$$\hat{Z}_{IN}=\sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{6}\frac{L}{l}\sum_{g=1}^{l}a_{ijkg}$$

where a_{ijkg} = weighted number of smolt traces indicating PSC entrance in the gth sampling interval $(g=1,\ldots,l)$ at the kth spatial stratum $(k=1,\ldots,6)$ in the jth hour $(j=1,\ldots,23)$ of the ith day $(i=1,\ldots,d)$.

Here, a_{ijkg} is the expanded number of smolt moving towards the entrance in a 2-minute interval in one of the six subareas of the PSC entrance. The variance of $\hat{Z}_{IN}$ can be computed as follows:

$$V\hat{a}r\left(\hat{Z}_{IN}\right)=\sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{6}\left[\frac{L^2\left(1-\frac{l}{L}\right)\hat{S}^2_{a_{ijk}}}{l}\right]$$

and where

$$\hat{S}^2_{a_{ijk}} = \frac{\sum_{g=1}^{l}\left(a_{ijkg} - \overline{a_{ijk}}\right)^2}{(l-1)}$$

$$\overline{a_{ijk}} = \frac{\sum_{g=1}^{l} a_{ijkg}}{l}.$$

$\hat{Z}_{OUT}$ and $V\hat{a}r\left(\hat{Z}_{OUT}\right)$ would be computed analogous to $\hat{Z}_{IN}$ but where

b_{ijkg} = weighted number of smolt traces indicating PSC entrance avoidance in the gth sampling interval $(g = 1,\ldots,l)$ at the kth spatial stratum $(k = 1,\ldots,6)$ in the jth hour $(j = 1,\ldots,23)$ of the ith day $(i = 1,\ldots,d)$.

Here, b_{ijkg} is the expanded number of unguided smolt detections in a 2-minute interval in one of the six subareas of the PSC entrance.

The PSC entrance efficiency would then be estimated by

$$PS\hat{C}EE = \frac{\hat{Z}_{IN}}{\hat{Z}_{IN} + \hat{Z}_{OUT}}.$$

The variance of $PS\hat{C}EE$ can be approximated by the Delta method where

$$V\hat{a}r\left(PS\hat{C}EE\right) = PS\hat{C}EE^2\left(1 - PS\hat{C}EE\right)^2 \cdot \left[\frac{V\hat{a}r\left(\hat{Z}_{IN}\right)}{\hat{Z}^2_{IN}} + \frac{V\hat{a}r\left(\hat{Z}_{OUT}\right)}{\hat{Z}^2_{OUT}} - \frac{2\,C\hat{o}v\left(\hat{Z}_{IN}, \hat{Z}_{OUT}\right)}{\hat{Z}_{IN}\hat{Z}_{OUT}}\right].$$

In this approach, the a_{ijkg} and b_{ijkg} are correlated because they are measured in the same sample volume of a transducer beam. The covariance between $\hat{Z}_{IN}$ and $\hat{Z}_{OUT}$ can be estimated by the formula

$$C\hat{o}v\left(\hat{Z}_{IN}, \hat{Z}_{OUT}\right) = \sum_{i=1}^{d}\sum_{j=1}^{23}\sum_{k=1}^{6}\left[\frac{L^2\left(1 - \frac{l}{L}\right)C\hat{o}v\left(a_{ijk}, b_{ijk}\right)}{l}\right]$$

and where

$$\hat{Cov}\left(a_{ijk}, b_{ijk}\right) = \frac{\sum_{g=1}^{l}\left(a_{ijkg} - \overline{a_{ijk}}\right)\left(b_{ijkg} - \overline{b_{ijk}}\right)}{(l-1)}.$$

The above formulas pertain to estimates when the 20-ft slot is used. When the 5-ft slot is in operation, only the middle pair of split-beams would be used to count the a_{ijkg}'s and b_{ijkg}'s for $k = 1,2$.

V. Evaluation of Hydroacoustic Techniques

A. Alternative Estimates of PSC Passage

At Unit #5, the number of smolt entering the PSC can be measured by either the numbers of smolt entering the PSC entrance (A) or by the numbers of smolt that passed through the PSC and into the turbine slots (C). Define

$\hat{A}_i$ = estimated number of smolt passing into the PSC entrance at Unit #5 on the ith day $(i = 1, \ldots, n)$;

$\hat{C}_{ij}$ = estimated number of smolt passing through the PSC and into the jth turbine slot of Unit #5 $(j = 1, \ldots, 3)$ on the ith day $(i = 1, \ldots, n)$;

and where

$$\hat{C}_i = \sum_{j=1}^{3} \hat{C}_{ij}.$$

If the sampling processes are nominal, then it would be expected that on the average

$$\begin{aligned} E\left(\hat{A}_i\right) &= E\left(\hat{C}_{i1} + \hat{C}_{i2} + \hat{C}_{i3}\right) \\ &= E\left(\hat{C}_i\right) \ \forall_i . \end{aligned} \tag{1}$$

The relationship (1) can be tested using a two-sample paired t-test of the form

$$t_{n-1} = \frac{\hat{\bar{d}} - 0}{\sqrt{\frac{s^2_{\hat{d}_i}}{n}}}$$

where

$$\hat{d}_i = \hat{A}_i - \hat{C}_i$$

$$\hat{\bar{d}} = \frac{\sum_{i=1}^{n} \hat{d}_i}{n}$$

$$s^2_{\hat{d}_i} = \frac{\sum_{i=1}^{n} \left(\hat{d}_i - \hat{\bar{d}}\right)^2}{(n-1)}$$

$n =$ number of days of data.

The P-value associated with the paired t-test should be computed and reported. A $(1-\alpha)100\%$ confidence interval for $\hat{\bar{d}}$ should also be computed of the form

$$\hat{\bar{d}} \pm t_{1-\frac{\alpha}{2}, n-1} \cdot \sqrt{\frac{s^2_{\hat{d}_i}}{n}}.$$

B. Evaluate Assumption of Uniform Smolt Distribution Within Turbine Intakes

The two uplooking transducers within each turbine slot of Unit #5 can be used to assess whether transducer location may influence estimates of PSC passage. Estimates of total daily PSC passage $\left(\hat{X}_i\right)$ could be calculated using left only $\left(\hat{X}_{Li}\right)$, right only $\left(\hat{X}_{Ri}\right)$, or the double-transducer array $\left(\hat{X}_{Di}\right)$. Statistical comparison of left-only versus right-only estimates could again be performed using a two-sample paired t-test of the form

$$t_{n-1} = \frac{\overline{d} - 0}{\sqrt{\frac{s_d^2}{n}}}$$

where

$$d_i = \hat{X}_{Li} - \hat{X}_{Ri}$$

$$\overline{d} = \frac{\sum_{i=1}^{n} d_i}{n}$$

$$s_d^2 = \frac{\sum_{i=1}^{n} \left(d_i - \overline{d}\right)^2}{(n-1)}$$

$n =$ number of days of data.

The P-value associated with the paired t-test should be computed and reported.

Seasonal estimates of total turbine passage should also be computed of the form

$$\hat{X}_L = \sum_{i=1}^{d} \hat{X}_{Li}$$

with associated variance

$$\hat{Var}\left(\hat{X}_L\right) = \sum_{i=1}^{d} \hat{Var}\left(\hat{X}_{Li}\right)$$

for $i = 1, \ldots, d$ days of sampling for left-only estimates. Estimates based on a right-only and double-transducer arrays should also be computed. These estimates will be empirically compared between transducer deployments, and 90% confidence intervals examined for overlap. Comparisons of estimates will be performed for each turbine intake slot and for the entire unit as a whole.

Within each turbine slot, there are also two downlooking transducers. An analogous analysis of left-only, right-only, and double-arrays for the downlooking

transducers can also be performed to determine whether transducer location affects in-turbine estimates of smolt passage under the PSC.

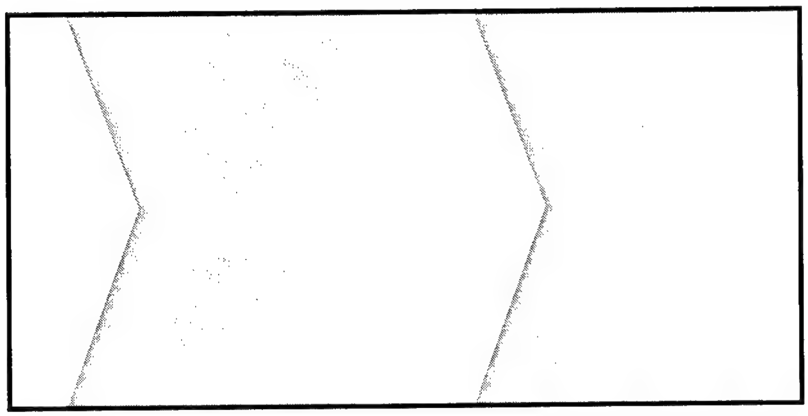
The up- and downlooking transducers within each intake provide a maximum area of insonification by considering the widest section of each beam (Figure 5). These "hourglass" zones of insonification can also be used to estimate total smolt passage. A third analysis of horizontal distribution can therefore be based on comparing left-only, right-only, and double-array estimates of total smolt passage using the statistical methods described above.

C. Evaluating Assumptions of Uniform Smolt Distribution Within PSC Slot

The PSC slot in front of turbine Unit #5 will have 3 pairs of uplooking/downlooking split-beam transducers (Figure 2a). The horizontal distribution within the entrance slot can be evaluated by comparing the passage estimates based on left-only, middle, and right-only pairs of transducers. Daily passage estimates would be computed by each of these three approaches. A two-way analysis of variance could then be used to test whether mean passage estimates for the three different estimators were equal. A degree-of-freedom table associated with the two-way ANOVA would be of the form depicted below:

Source	df
Total	$3d$
Mean	1
Total_{COR}	$3d-1$
Days	$d-1$
Estimators	2
Error	$2(d-1)$

Figure 5. Schematic of hourglass insonification zones formed by the uplooking and downlooking transducers within turbine slot intakes.



The ANOVA tests the null hypothesis

$$H_o: \quad \mu_{\hat{A}_{Li}} = \mu_{\hat{A}_{Mi}} = \mu_{\hat{A}_{Ri}}$$

where $\hat{A}_{Li}$ is the estimate of PSC passage based on the left transducer only for the ith day. Other estimates are defined similarly.

Seasonal estimates of total PSC passage based on left-only transducers should be computed of the form

$$\hat{A}_L = \sum_{i=1}^{d} \hat{A}_{Li}$$

with associated variance

$$V\hat{a}r\left(\hat{A}_{Li}\right) = \sum_{i=1}^{d} V\hat{a}r\left(\hat{A}_{Li}\right)$$

for $i = 1, \ldots, d$ days of sampling. Similar seasonal estimates of PSC passage should be computed for middle and right-only and total arrays. These estimates will be empirically compared between transducer deployments and 90% confidence intervals examine for overlap.

Analogous computations could be performed using the three uplooking or just the three downlooking split-beam transducers to determine whether transducer location affects estimates of smolt passage within the PSC.

VI. Experimental Test of PSC Slot Sizes 5 Ft and 20 Ft

A. Experimental Design

During 1999, two different PSC slot sizes will be tested to assess effects on smolt passage. The experimental design will be a randomized block design, each treatment

condition will be evaluated for 2 consecutive days within the blocks. Hence, an experimental block will consist of 4 consecutive days (Table 1). During the spring test, the experiment will consist of 10 blocks. The summer test will also consist of 10 blocks.

Tests of effects will be based on a two-sample, paired t-test (or equivalently, a two-way ANOVA with two treatments). The two-way ANOVA will be of the form depicted by the degree-of-freedom table below:

Source	df
Total	$2B$
Mean	1
Total_{COR}	$2B-1$
Blocks	$B-1$
Treatments	1
Error	$B-1$

where B = number of test blocks.

A weighted ANOVA, weighting inversely proportional to the variance estimates, would account for unequal measurement errors.

B. Response Variables in PSC Test

The effects of slot size (e.g., 5 ft versus 20 ft) will be evaluated using 7 different but related performance measures. The response variables used in the PSC trials will include the following:

1. PSC efficiency at Unit #5: $\hat{PSCE}_5$
2. PSC efficiency at Unit #6: $\hat{PSCE}_6$
3. Combined PSC efficiency at Units #5 and #6: $\hat{PSCE}_{5-6}$
4. PSC effectiveness at Unit #5: $\hat{PSCF}_5$
5. PSC effectiveness at Unit #6: $\hat{PSCF}_6$

Table 1. Experimental design for the 1999 evaluation of the Bonneville First Powerhouse Prototype Surface Collector. Treatments are the slot widths of PSC entrances. Changes will be made between 0700 and 1000 hr on change dates.

Date Spring	Julian Date	Day of Week	PSC Opening (ft)	PH1 Action Item	PSC Block	Date Summer	Julian Date	Day of Week	PSC Opening (ft)	PH1 Action Item	PSC Block
4/19/99	109	Mon	20		1	6/07/99	158	Mon	20		1
4/20/99	110	Tue	20		1	6/08/99	159	Tue	20		1
4/21/99	111	Wed	5	change	1	6/09/99	160	Wed	5	change	1
4/22/99	112	Thu	5		1	6/10/99	161	Thu	5		1
4/23/99	113	Fri	5		2	6/11/99	162	Fri	5		2
4/24/99	114	Sat	5		2	6/12/99	163	Sat	5		2
4/25/99	115	Sun	20	change	2	6/13/99	164	Sun	20	change	2
4/26/99	116	Mon	20		2	6/14/99	165	Mon	20		2
4/27/99	117	Tue	20		3	6/15/99	166	Tue	5	change	3
4/28/99	118	Wed	20		3	6/16/99	167	Wed	5		3
4/29/99	119	Thu	5	change	3	6/17/99	168	Thu	20	change	3
4/30/99	120	Fri	5		3	6/18/99	169	Fri	20		3
5/01/99	121	Sat	20		4	6/19/99	170	Sat	20		4
5/02/99	122	Sun	20		4	6/20/99	171	Sun	20		4
5/03/99	123	Mon	5	change	4	6/21/99	172	Mon	5	change	4
5/04/99	124	Tue	5		4	6/22/99	173	Tue	5		4
5/05/99	125	Wed	5		5	6/23/99	174	Wed	5		5
5/06/99	126	Thu	5		5	6/24/99	175	Thu	5		5
5/07/99	127	Fri	20	change	5	6/25/99	176	Fri	20	change	5
5/08/99	128	Sat	20		5	6/26/99	177	Sat	20		5
5/09/99	129	Sun	20		6	6/27/99	178	Sun	5	change	6
5/10/99	130	Mon	20		6	6/28/99	179	Mon	5		6
5/11/99	131	Tue	5	change	6	6/29/99	180	Tue	20	change	6
5/12/99	132	Wed	5		6	6/30/99	181	Wed	20		6
5/13/99	133	Thu	20	change	7	7/01/99	182	Thu	5	change	7
5/14/99	134	Fri	20		7	7/02/99	183	Fri	5		7
5/15/99	135	Sat	5	change	7	7/03/99	184	Sat	20	change	7
5/16/99	136	Sun	5		7	7/04/99	185	Sun	20		7
5/17/99	137	Mon	20	change	8	7/05/99	186	Mon	20		8
5/18/99	138	Tue	20		8	7/06/99	187	Tue	20		8
5/19/99	139	Wed	5	change	8	7/07/99	188	Wed	5	change	8
5/20/99	140	Thu	5		8	7/08/99	189	Thu	5		8
5/21/99	141	Fri	20	change	9	7/09/99	190	Fri	5		9
5/22/99	142	Sat	20		9	7/10/99	191	Sat	5		9
5/23/99	143	Sun	5	change	9	7/11/99	192	Sun	20	change	9
5/24/99	144	Mon	5		9	7/12/99	193	Mon	20		9
5/25/99	145	Tue	5		10	7/13/99	194	Tue	20		10
5/26/99	146	Wed	5		10	7/14/99	195	Wed	20		10
5/27/99	147	Thu	20	change	10	7/15/99	196	Thu	5	change	10
5/28/99	148	Fri	20		10	7/16/99	197	Fri	5		10

6. Combined PSC effectiveness at Units #5 and #6: $P\hat{S}CF_{5-6}$

7. PSC entrance efficiency at Unit #5: $PS\hat{C}EE$

P-values for the tests of effects will be reported along with treatment means and associated standard errors.

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Gene R. Ploskey, Peter N. Johnson, William T. Nagy, Carl R. Schilt, Larry R. Lawrence, Deborah S. Patterson, John R. Skalski

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14. ABSTRACT

This research effort had two primary objectives: (a) to test hydroacoustic sampling proposed for the year-2000 evaluation of the prototype surface collector (PSC); and (b) to evaluate a split-beam deployment upstream of a PSC slot and determine whether it provides reasonable estimates of fish passage relative to estimates from in-turbine transducers. For in-turbine passage, two pairs of up- and down-looking single-beam transducers mounted on trashracks in each of the three slots in Unit 5 were used to estimate the number of juvenile salmon passing under and into the PSC. Each opposing pair of transducers was fast multiplexed at a rate of 20 pings per second (10 each) for a 2-min period before switching to another opposing pair. All in-turbine counts of fish were spatially expanded based upon the ratio of one-half of the intake width to the diameter of the hydroacoustic beam at the midrange of the detected fish. Fish passage into and fish behavior in front of the PSC were monitored with three pairs of up- and down-looking split-beam transducers mounted on a steel frame and placed upstream of the PSC trashrack at turbine intake 5b. Two of the transducer pairs were located 2 m to either side of the middle of the slot to sample fish on the north and south sides of the PSC entrance. The third pair was placed in the middle of the slot to sample fish near the center of the entrance. Each pair of opposing transducers was fast-multiplexed at 10 pings per second each for 20 min per hour.
(Continued)

15. SUBJECT TERMS

Bonneville Dam	Fixed-aspect hydroacoustics	Prototype surface collector
Fish guidance efficiency	Hydroacoustic detectability	
	Juvenile salmon	

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U.S. Army Engineer Research and Development Center, Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

AscI Corporation
1365 Beverly Road
McLean, VA 22101

U.S. Army Engineer District, Portland
333 SW First Avenue, Tenth Floor
Portland, OR 97204-3495

DynTel, Inc.
3530 Manor Drive
Vicksburg, MS 39180

School of Aquatic and Fishery Sciences
University of Washington
1122 Boat Street, NE
Seattle, WA 98105

14. ABSTRACT (Concluded)

Twenty-three hours of hydroacoustic data were collected per day for a total of 36 days in the spring and 40 days in the summer. In-turbine counts of fish passing through the PSC were not reliable during 20-ft (6-m) slot treatments because of dense acoustic noise created by turbulence within the PSC. During 20-ft (6-m) slot treatments, large volumes of entrained air were concentrated in the upper water column of the turbine intake, and high densities of echoes from the air reduced the ability to distinguish fish from noise with the up-looking, in-turbine beams. Fortunately, split-beam transducers immediately upstream of the PSC openings provided counts that were highly correlated with in-turbine counts during 5-ft (1.5-m) slot treatments in spring and summer. Consequently, split-beam counts were substituted to estimate numbers of guided fish for 20-ft (6-m) treatments in both seasons.

Spring: Efficiency of the PSC (guided fish/guided + unguided fish) with a 20-ft slot (85 percent) was significantly higher ($Pr \geq 0.004$; $N = 9$) than with a 5-ft slot (70 percent). The 20-ft slot yielded significantly higher numbers ($Pr \geq 0.004$; $N = 9$) of guided fish than the 5-ft slot. We detected no difference in numbers of unguided fish among 20-ft and 5-ft slot treatments. PSC effectiveness (proportion of fish collected relative to the proportion of flow passed) was significantly higher ($Pr \geq 0.008$; $N = 9$) during 5-ft treatments than during 20-ft treatments. Entrance efficiencies (proportion of fish entering the slot relative to number passing within about 3 m of the opening) were significantly higher ($Pr \geq 0.008$; $N = 9$) with 20-ft slots (32 percent) than with 5-ft slots (30 percent). Entrance efficiencies with split-beam transducers may be low and biased because fish that passed through the beam in lateral or upstream directions may be counted more than once while fish passing toward the opening less than 1 m away are unlikely to be counted more than once. Eighty percent of the fish during 5-ft treatments and 93 percent of the fish during 20-ft treatments detected by the split-beams and moving in a downstream direction were distributed above the elevation of the PSC floor.

Summer: Efficiencies did not differ among slots (70 and 67 percent for 20- and 5-ft slots, respectively). No difference was detected in numbers of guided or unguided fish among 20-ft and 5-ft slots. Five-foot treatments resulted in significantly higher PSC effectiveness ($Pr \geq 0.002$; $N = 10$) than for 20-ft treatments. Entrance efficiencies were significantly higher ($Pr \geq 0.002$; $N = 10$) with 20-ft slots (36 percent) than with 5-ft slots (30 percent). Eighty percent of the fish during 5-ft treatments and 92 percent of the fish during 20-ft treatments detected by the split-beams and moving in a downstream direction were distributed above the elevation of the PSC floor.

To determine spatial coverage for sampling of the PSC in 2000, differences of guided and unguided fish passage among and within turbine intakes of Unit 5 were tested by slot treatment. Comparisons of guided fish for 20-ft treatments are not reported due to the previously mentioned noise problems. In spring, no differences in guided fish passage for 5-ft treatments or unguided fish passage for either treatment were detected among the three intakes when passage data were summed by day ($N = 18$). Summertime among-slot comparisons yielded significant differences ($P = 0.0001$; $N = 20$) in guided fish passage with 5-ft slots and unguided fish passage with both slot-width treatments. Within-slot comparisons resulted in detection of significant differences among north and south guided fish passage estimates for 5-ft and unguided fish passage with 5- and 20-ft slot treatments for both seasons. Detected differences in passage estimates among intakes suggest that every intake should be sampled in 2000. Smaller differences among positions within intakes may be most efficiently addressed by stratified random sampling of transducer positions rather than deploying 36 transducers to sample all positions. Given noise limitations of sampling guided fish in turbines during 20-ft slot treatments and the high correlation between split-beam and in-turbine estimates during 5-ft slot treatments, using in-turbine sampling to estimate unguided fish passage and split-beam counts to estimate guided-fish passage are proposed.